Viavattene, Christophe ORCID logoORCID: https://orcid.org/0000-0002-4358-5411, Micou, Paula, Owen, Damon, Priest, Sally J. ORCID logoORCID: https://orcid.org/0000-0003-2304-1502 and Parker, Dennis J. (2015) Library of Coastal Vulnerability Indicators guidance document. Project Report. Middlesex University. . [Monograph]

RISC-KIT

Resilience-Increasing Strategies for Coasts – Toolkit

www.risckit.eu

Library of Coastal Vulnerability Indicators

Guidance Document

Deliverable No: D.2.2 – Coastal Vulnerability Indicator Library
Ref.: WP2 - Task 2.2
Date: March 2015

Grant Agreement No. 603458
DG Research –FP7-ENV-2013-two-stage

This project has received funding from the European Union's Seventh Programme for Research, Technological Development and Demonstration under Grant Agreement n° [603458]. This publication reflects the views only of the author's, and the European Union cannot be considered liable for any use that may be made of the information contained therein.

Deliverable Title	D.2.2 – Coastal Vulnerability Indicator Library
Filename	RISC-KIT_D.2.2_CVIL_Guidance_Document
Authors	Dr Christophe Viavattene (Flood Hazard Research Centre, Middlesex University) Dr Ana Paula Micou (Flood Hazard Research Centre, Middlesex University) Damon Owen (Flood Hazard Research Centre, Middlesex University) Dr Sally Priest (Flood Hazard Research Centre, Middlesex University) Prof Dennis Parker (Flood Hazard Research Centre, Middlesex University)
Contributors	Dr Tom Spencer (The Cambridge Coastal Research Unit, University of Cambridge) Dr Iris Moller (The Cambridge Coastal Research Unit, University of Cambridge) Dr Anna McIvor (The Cambridge Coastal Research Unit, University of Cambridge)
Date	31/03/2015

Prepared under contract from the European Commission
Grant Agreement No. 603458
Directorate-General for Research & Innovation (DG Research), Collaborative project, FP7-ENV-2013-two-stage

Start of the project: 01/11/2013
Duration: 42 months
Project coordinator: Stichting Deltares, NL

Dissemination level

X	PU	Public
	PP	Restricted to other programme participants (including the Commission Services)
	RE	Restricted to a group specified by the consortium (including the Commission Services)
	CO	Confidential, only for members of the consortium (including the Commission Services)

Deliverable status version control

Version	Date	Author	Review
1.0	28/02/2015	Dr Christophe Viavattene (Flood Hazard Research Centre, Middlesex University)	Prof José Jiménez (Polytechnic University of Catalonia) Prof Edmund Penning-Rowsell (Flood Hazard Research Centre, Middlesex University)
1.1	31/03/2015	Dr Christophe Viavattene (Flood Hazard Research Centre, Middlesex University)	

Table of Contents

1 Introduction 9
1.1 Project objectives 9
1.2 Project structure 10
1.3 Deliverable context and objective 12
1.4 Approach 13
1.5 Outline of the report 14
2 General guidance and definitions 15
3 How to use the Library 19
3.1 Library Structure 19
3.2 Methods and Options 21
4 Vulnerability Indicators for the Built Environment 23
4.1 Flood Damage Curves 23
4.1.1 Introduction to flood damage curves 23
4.1.2 Method A: Using existing flood damage curves 24
4.1.3 Method B: Developing flood damage curves 25
4.2 Building Collapse 31
4.2.1 Introduction to building collapse 31
4.2.2 Method A for building collapse 35
4.2.3 Method B for building collapse 36
4.3 Erosion Vulnerability Indicator 38
4.3.1 Introduction to Erosion 38
4.3.2 Erosion Vulnerability Indicator 40
5 Vulnerability Indicators for the population 42
5.1 Social Vulnerability 42
5.1.1 Introduction to Social Vulnerability Indicators 42
5.1.2 Method A: Using existing indicators 45
5.1.3 Method B: Developing new Social Vulnerability Indicators 46
5.2 Risk to Life 59
5.2.1 Introduction to risk to life 59
5.2.2 Methodology for assessing the potential risk to life during flood events 61
6 Vulnerability Indicators for ecosystems 66
6.1 Introduction to ecosystem vulnerability indicator 66
6.2 Methodology for assessing ecosystems vulnerability 67
6.2.1 Method A: Using existing indicators 69
6.2.2 Method B: Developing or tailoring Ecosystem Vulnerability Indicators 71
7 Systemic Vulnerability Indicators 74
7.1 Critical Infrastructure 76
7.2 Business Disruption 80
8 Disasters Risk-Reduction Measures 88

8.1 Sources of information 88
8.2 The inclusion of DRRs in the assessment of Systemic Vulnerability 92
9 Appendices 96

List of Figures

Figure 1.1: Conceptual drawing of the CRAF (top panel), the EWS (middle panel) and the DSS (bottom panel) 11

Figure 1.2: Case study sites (stars), RISC-KIT case study site partners (blue solid dots) and non-case study partners (red open circles) 12

Figure 3.1: A snapshot of the introduction page 19

Figure 3.2: The Library is specifically tailored to each case study country 20

Figure 3.3: The main categories of indicators 20

Figure 3.4: General Library structure 21

Figure 3.5: A snapshot of the Methods and Options used for flood depth-damage curves 22

Figure 4.1: An example of an 'absolute' (left) and 'relative' depth-damage curve (right) 24

Figure 4.2: An example of a field survey form used to obtain empirical data from flooded residents 27

Figure 4.3: An example of a matrix from Kelman (2002, 244), showing total building collapse ('DS5') at 2.5m flood depth and 0.0 m/s velocity 33

Figure 4.4: The adjusted curve used for New Orleans 35

Figure 4.5: A snapshot of "Method A for Building Collapse" from the Library showing the adapted Karvonen et al. (2000) dataset. 35

Figure 4.6: HR Wallingford's indoor Tsunami Simulator 37

Figure 4.7: Controlled outdoor testing conditions 37

Figure 4.8: Evacuation of a building threatened by erosion 39

Figure 4.9: Distance Thresholds used to define the Erosion Vulnerability Indicator 41

Figure 5.1: Flowchart of the methodologies for Social Vulnerability 44

Figure 5.2: SFVI by Output Areas. North Norfolk (England) 44

Figure 5.3: Histogram showing normal distribution for the case of unemployment in North Norfolk (UK) in 2011 49

Figure 5.4: SFVI by Census sections. Maresme region (Barcelona, Spain) 52

Figure 6.1: Example for "Sand Dunes" 72

Figure 7.1: Systemic vulnerability 75

Figure 7.2: Snapshot of the template page illustrating the 5-step approach 76

Figure 7.3: Snapshot of the "Step 1 Stakeholders Table" 77

Figure 7.4: Snapshot of the "Step 2 Assets table" 77

Figure 7.5: Example of a flow diagram for the electricity network 79

Figure 7.6: Example map of electricity assets based on the schematic for Step 3 79

Figure 7.7: Example of a hotel supply chain 81

Figure 7.8: Snapshot of the “Business Disruption Template page” illustrating the 6-step approach......82

Figure 7.9: A snapshot of the “Step 3 Asset Matrix”......83

Figure 7.10:Example of an inter-dependency diagram for a coastal business setting distinguishing between coastal infrastructure assets and business assets......85

Figure 7.11: Example of a map of coastal infrastructure and business assets (without links in the case)......86

Figure 7.12: Example of map of business assets and inter-dependencies with the locality mapped in the previous step......86

Figure 8.1: Examples of the complexity of DRRs working in combination to impact upon the percentage of the population evacuating prior to a tidal surge event......91

List of Tables

Table 4.1: A snapshot of a susceptibility curve for building fabric items (not all flood depths (in cm) shown) 28

Table 4.2: Example components for building fabric and inventory items....30

Table 4.3: Flood actions on buildings (Foerster et al., 2009 after Kelman and Spence, 2004)....32

Table 4.4: The Karvonen et al. (2000) damage matrix will form Method A for the Building Collapse section of the Library. 34

Table 4.5: Erosion Vulnerability Indicator....41

Table 5.1: Characteristics, variables and data to apply the SFVI 47

Table 5.2: Example of variables used for the SFVI applied in England 49

Table 5.3: Example of output for the Barcelona region 51

Table 5.4: List of indicators most commonly found in the literature, and usually available from national Census data 54

Table 5.5:FLOODsite Risk to Life method....62

Table 5.6: Simplified table in the Library 65

Table 6.1: Scale used for the Environmental Vulnerability Indicator (THESEUS Project) 68

Table 6.2: Ecosystem Vulnerability Indicators included in the Library....70

Table 6.3: Indicator for yield loss....73

Table 8.1: The DRR measures included in the Library mapped onto the categories of vulnerability....94

Publishable Summary

The Resilience-Increasing Strategies for Coasts – Toolkit (RISC-KIT) FP7 EU project (2013-2017) aims to produce a set of three innovative and EU-coherent open-source and open-access methods, tools and management approaches (the RISC-KIT) in support of coastal managers, decision-makers and policy makers to reduce risk and increase resilience to low-frequency, high impact hydro-meteorological events. Risk is defined within this project as the product of the probability of a hazard, the exposure of receptors and their vulnerability. Representing the vulnerability and the potential role of DRR in their reduction is crucial for supporting the decision. As such a specific task of the RISC-KIT project (Task 2.2) is dedicated to developing a Library of Vulnerability Indicators to input in the RISC-KIT Toolkit and to test the tools on 11 case studies. The deliverable "Coastal Vulnerability Indicator Library" is composed of a Microsoft Excel database and a guidance document. The deliverable introduces the necessary concepts and methods, provides a review and a collection of existing indicators and proposes methodologies for developing new indicators. The Library has been constructed around four categories: Built Environment, Population, Ecosystem and Systems. The Library also identifies Disaster Reduction Measures influencing vulnerability and proposes methods to include within the assessment of vulnerability.

Executive Summary

The Resilience-Increasing Strategies for Coasts – Toolkit (RISC-KIT) EU FP7 project (2013-2017) aims to produce a set of three innovative and EU-coherent open-source and open-access methods, tools and management approaches (the RISC-KIT) in support of coastal managers, decision-makers and policy-makers to reduce risk and increase resilience to low-frequency, high impact hydro-meteorological events. Risk is defined within this project as the product of the probability of a hazard, the exposure of receptors and their vulnerability. Representing the vulnerability and the potential role of Disaster-Risk Reduction is crucial for supporting the decision. As such, a specific task of the RISC-KIT project (Task 2.2) is dedicated to developing a Library of Vulnerability Indicators to input in the RISC-KIT Toolkit and to test these tools on 11 case studies. The deliverable "Coastal Vulnerability Indicator Library" is composed of:

- This Guidance Document, explaining how to use the Library, but also introducing the necessary concepts and methods to understand and to develop the vulnerability indicators;
- A Microsoft Excel database, containing existing indicators, methodologies for developing indicators and links to the Guidance Document.

The Library has been constructed using four categories: the Built Environment, the Population, the Ecosystem and Systemic. For each of these, the Library provides a review of existing vulnerability indicators. As their availability and quality varies from one country to another, a standardised series of methods (Method A and B) and Options have been designed:

- Method A: Appropriate vulnerability indicators exists and are the most suitable for use;
- Method B: Either an available indicator is not suitable for use or no indicator exists domestically or internationally. In this instance, an indicator has to be developed by the user.

<u>Built Environment</u>

The Built Environment category considers the direct damage to tangible assets. These include damage to buildings and other assets, such as vehicles and caravans. However, most vulnerability indicators have only been developed for buildings and as such the Library essentially provides existing depth-damages curves as building vulnerability indicators. If not available, the Library proposes either an adaptation of existing curves or the development of new ones using an empirical or synthetic approach.

The Library also contains indicators used to assess the collapse of assets due to high depth-velocity flooding or waves in the form of a matrix, and/or due to erosion conditions based on a distance to the shoreline threshold approach.

<u>Population</u>

The Population category considers the impacts on people. Two main indicators are included: A Social Vulnerability indicator and a Risk to Life indicator. A Social Vulnerability indicator measures the relative vulnerability of the population to long term health impacts and their financial recovery from coastal events. The indicator is a composite indicator based on the population characteristics and can be developed using population statistics.

The Risk to Life matrix indicates the potential injury or fatality during an event for a specific location based on the hazard characteristics (depth-velocity), the site characteristics (e.g. bungalow, lack of shelters) and certain characteristics of the population.

Ecosystem

The Ecosystem category considers potential impacts of coastal events on various coastal ecosystems, such as sand dunes, fresh water marshes, agricultural land or woodland. An Ecosystem Vulnerability Indicator estimates the potential change to an ecosystem which induces a temporary or permanent loss of ecosystem services. The Ecosystem Vulnerability Indicator is generic and is based on a 4-scale qualitative approach. Although this may be suitable for a quick introductory assessment, a comprehensive analyse requires an in-depth field study to understand the complexity and the specificity of a habitat.

Systemic

A system refers in general to a set of elements interconnected and somehow organized, providing functions and outputs; examples include an electricity network, a transport network but also business or emergency services systems. As such, direct hazard losses might propagate within and between different systems generating other losses beyond the hazard area, and thus delaying the recovery. A template is proposed to the end user to assist with identifying which systems to consider, how to characterize their assets and networks and, finally, how to analyse and reveal descriptively the systemic vulnerability. The approach has been developed for critical infrastructure and for business disruption but could be adapted to other systems where necessary.

Disaster-Risk Reduction Measures

Certain Disaster-Risk Reduction (DRRs) measures might influence different categories of vulnerability (e.g. property resistance measures, flood warning). The Library identifies such measures and specifies three ways in which the mitigative effects of DRRs can been included within the assessment of vulnerability: (1) Modifying the indicator, (2) Reducing the value of the indicator output (3) Recalculating an input value to an indicator, but without indicator modification.

1 Introduction

Recent and historic low-frequency, high-impact events such as Xynthia (impacting France in 2010), the 2011 Liguria (Italy) Flash Floods and the 1953 North Sea storm surge which inundated parts of the Netherlands, Belgium and the UK have demonstrated the flood risks faced by exposed coastal areas in Europe. Typhoons in Asia (such as Typhoon Haiyan in the Philippines in November 2013), hurricanes in the Caribbean and Gulf of Mexico, and Superstorm Sandy, impacting the northeastern U.S.A. in October 2012, have demonstrated how even larger flooding events pose a significant risk and can devastate and immobilize large cities and countries.

These coastal zone risks are likely to increase in the future (IPPC, AR5) which requires a re-evaluation of coastal disaster risk reduction (DRR) strategies and a new mix of prevention (e.g. dike protection), mitigation (e.g. limiting construction in flood-prone areas; eco-system based solutions) and preparedness (e.g. Early Warning Systems, EWS) (PMP) measures. Even without a change in risk due to climate or socio-economic changes, a re-evaluation is necessary in the light of a growing appreciation of ecological and natural values which drive ecosystem-based or Nature-based flood defense approaches. In addition, as free space is becoming sparse, coastal DRR plans need to be spatially efficient, allowing for multi-functionality.

1.1 Project objectives

In response to these challenges, the RISC-KIT project aims to deliver a set of open-source and open-access methods, tools and management approaches to reduce risk and increase resilience to low-frequency, high-impact hydro-meteorological events in the coastal zone[1]. These products will enhance forecasting, prediction and early warning capabilities, improve the assessment of long-term coastal risk and optimise the mix of PMP-measures. Specific objectives are:

1. Review and analysis of current-practice coastal risk management plans and lessons-learned of historical large-scale events;
2. Collection of local socio-cultural-economic and physical data at case study sites through end-user and stakeholder consultation to be stored in an impact-oriented coastal risk database;
3. Development of a regional-scale coastal risk assessment framework (CRAF) to assess present and future risk due to multi-hazards ((Figure 1.1), top panel);
4. Development of an impact-oriented Early Warning and Decision Support System (EWS/DSS) for hot spot areas consisting of: i) a free-ware system to predict hazard intensities using coupled hydro-meteo and morphological models and ii) a Bayesian-based Decision Support System which integrates hazards and socio-economic, cultural and environmental consequences ((Figure 1.1), centre panel);
5. Development of potential DRR measures and the design of ecosystem-based and cost-effective, (non-)technological DRR plans in close cooperation with end-users for a

[1] Van Dongeren, A., Ciavola, P., Viavattene, C., De Kleermaeker, S., Martinez, G., Ferreira, O., Costa, C. and McCall, R. (2014) RISC-KIT: Resilience-Increasing Strategies for Coasts – toolkit. In: Green, A.N. and Cooper, J.A.G. (eds.), Proceedings 13th International Coastal Symposium (Durban, South Africa), Journal of Coastal Research, Special Issue (66). ISSN 0749-0208. 6 p.

diverse set of case study sites on all European regional seas and on one tropical coast (Figure 1.1: bottom panel);
6. Application of CRAF and EWS/DSS tools at the case study sites to test the DRR plans for a combination of scenarios of climate-related hazard and socio-economic vulnerability change and demonstration of the operational mode;
7. Development of a web-based management guide for developing integrated DRR plans along Europe's coasts and beyond and provide a synthesis of lessons learned in RISC-KIT in the form of policy guidance and recommendations at the national and EU level.

The tools are to be demonstrated on case study sites on a range of EU coasts in the North- and Baltic Sea Region, Atlantic Ocean, Black Sea and Mediterranean Sea, and one site in Bangladesh, see Figure 1.2. These sites constitute diverse geomorphic settings, land use, forcing, hazard types and socio-economic, cultural and environmental characteristics. All selected regions are most frequently affected by storm surges and coastal erosion. A management guide of PMP measures and management approaches will be developed. The toolkit will benefit forecasting and civil protection agencies, coastal managers, local government, community members, NGOs, the general public and scientists.

1.2 Project structure

The project is structured into seven Work Packages (WP) starting with WP1 on 'Data collection, review and historical analysis'. WP2–4 will create the components of the RISC Toolkit containing an 'Improved method for regional scale vulnerability and risk assessment' (WP2), 'Enhanced early warning and scenario evaluation capabilities for hot spots' (WP3) as well as 'New management and policy approaches to increase coastal resilience' (WP4). The Toolkit will be tested through 'Application at case study sites' (WP5). WP6 will be responsible for 'Dissemination, knowledge transfer and exploitation' and 'Coordination and Management' are handled in WP7.

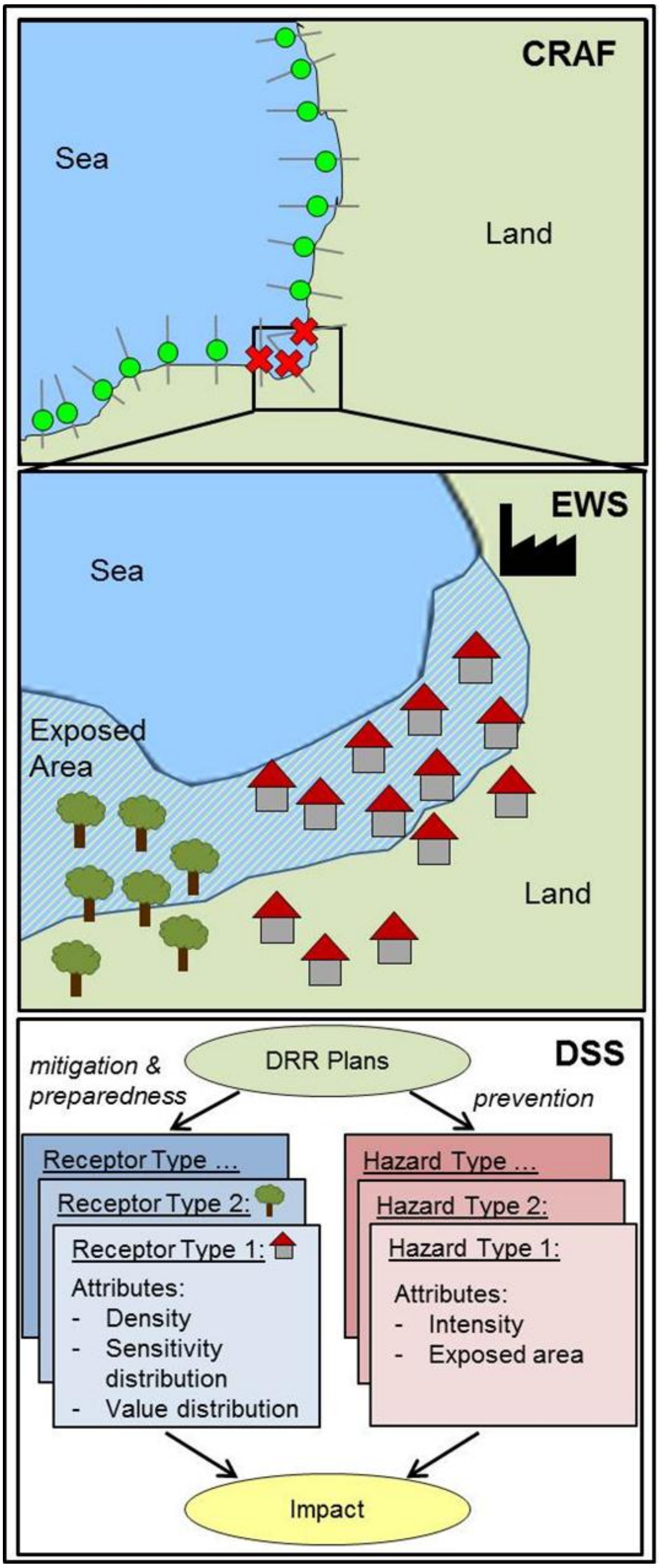


Figure 1.1: Conceptual drawing of the CRAF (top panel), the EWS (middle panel) and the DSS (bottom panel)

Figure 1.2: Case study sites (stars), RISC-KIT case study site partners (blue solid dots) and non-case study partners (red open circles)

1.3 Deliverable context and objective

The current deliverable 2.2 is part of WP2. The objectives of WP2 are to develop a:

- Coastal Hazard Assessment module to assess the magnitude of hazards induced by the impact of extreme hydro-meteorological events in the coastal zone at a regional scale (O(100 km));
- Set of Coastal Vulnerability Indicators for the receptors exposed to coastal hazards;
- Coastal Risk Assessment Framework (CRAF) for extreme hydro-meteorological events which, integrating hazards and vulnerability inputs, can be used to assess potential impacts and identify hot spot areas where detailed models can be applied.

This deliverable constitutes a Library of Coastal Vulnerability Indicators: ecosystems, built environment, human population, critical infrastructure and the overall characteristics of the coastal system. The Library includes data at European, national and local levels if available. This deliverable addresses the objective of WP2 and Project Objective 3 "Development of a regional-scale coastal risk assessment framework (CRAF) to assess present and future risk due to multi-hazard" by providing methodologies and indicators to assess coastal impact.

DOW *Verbatim* Text for Task 2.2 Coastal Vulnerability Indicators

The objective of this task is to develop a library of vulnerability indicators (Milestone 3 and D2.2). The main categories addressed in the library will be the ecosystems, built environment, human population, critical infrastructure and the overall characteristics of the coastal system. Current methods to develop vulnerability indicators will be reviewed. Existing indicators available at European and national level will also be collected to provide generic vulnerability indicators for these scales. To better consider the regional context and to convert generic indicators into regional and local indicators when necessary, local knowledge will be derived from RISC-KIT case study sites (Task 1.2). In particular, the question of extreme and unusual hazard characteristics and vulnerability changes will be addressed in order to account for irreversible impacts such as building collapse, risk to life, or exceedance of ecological thresholds. To properly assess how the coastal system will recover from an event, coastal system vulnerability indicators will be developed following a complex systems approach. This approach accounts for external factors such as the characteristics of the hazard, the nature of the surrounding environment, and the existence of prevention, mitigation and preparedness measures. The objective here is not to limit the vulnerability assessment to the relation between individual units and the hazard but rather to understand how the coastal system is vulnerable as a whole due to regional setting and existent DRR measures.

1.4 Approach

The notion of risk is defined within this project as the product of the probability of a hazard and its consequences. These consequences (or impacts) are composed of two factors: the exposure of receptors and their vulnerability (the receptor value and their sensitivity to experience harm). Representing the vulnerability of different receptors and the potential role of DRR is crucial for assessing such risk and supporting the decision. The main objective of the Library is to provide a set of vulnerability indicators which could be used as inputs to the RISC-KIT (i.e. CRAF, DSS) and its application to 11 pilot case studies[2]. It was originally considered to address five categories in the Library: the ecosystems, the built environment, the human population, critical infrastructure and the overall characteristics of the coastal system. Three categories (ecosystems, built environment and the population) have been kept as such within the Library. However critical infrastructure has been included in a broader category entitled "Systemic" which also includes a methodology for assessing the vulnerability of economic activities due to business disruption. Defining the overall vulnerability of the system remains complex as it requires considering the vulnerability of individual components of a system and their

[2] Bocca Di Magra (IT), Kiel Fjord (DE), Kristianstad Municipality (SE), La Faute Sur Mer (FR), North Norfolk (GB), Porto Garibaldi (IT), Ria Formosa (PT), Tordera Delta (ES),Varna (BG), Zeebrugge (BE) and Sandwip (BD)

interactions; each system, in its nature, is case-specific and depends on the regional setting. Therefore, it could not be addressed in a simple manner within the Library but will be further considered within the CRAF in Task 2.3 where a complex system approach will be developed to assess potential systemic impacts and recovery. Within each category, different vulnerability indicators have been reviewed to assess the main impacts (e.g. flood damages, agricultural losses etc.) but also the irreversible impacts resulting from extreme and unusual hazard characteristics (e.g. building collapse, risk to life and loss of ecosystem). The objective of the task was to review existing indicators and the methodologies used to develop them. As such a review of existing indicators has been completed. The Library includes these indicators unless licence restrictions prohibit their publication. In such cases, information on how to access them is instead provided. For certain countries at a national or lower scale no indicators are available. In such cases, the Library provides for each indicator a methodology to develop appropriate vulnerability indicators such as it would be possible to use the tools developed within the project at regional scale based on local knowledge gathered in WP1.2 of the RISC-KIT project. It is, therefore, expected that the Library will be populated with new case study-specific indicators developed by the partners in WP5 ("Application at case study sites") by the end of the project or, the Flood Directive taking effect, by other users following this project. As part of the task the question of how DRR measures may influence vulnerability has also been addressed. Based on WP4 inputs, the relevant DRR measures were selected and methodologies on how to represent their effect on vulnerability have been described.

The deliverable is composed of:

- This Guidance Document explaining how to use the Library but also introducing the necessary concepts and methods to understand and to develop the vulnerability indicators;
- A Microsoft Excel database containing existing indicators, methodologies for developing indicators and links to the Guidance Document.

1.5 Outline of the report

The document is structured in eight sections. Section 2 provides general guidance and definitions to help the reader navigate through the deliverable. Section 3 explains how to use the Excel Library and access the data. Sections 4 to 7 address the different categories (Built Environment, Population, Ecosystems and Systemic). In each of these, the considered vulnerabilities and related impacts are explained, methodologies are reviewed and the "how to proceed" is detailed. Section 8 introduces the Disaster-Risk Reduction measures.

2 General guidance and definitions

Within the guidance document and the Excel Library, users will find concepts and terminology used for the purpose of this project which may have a different significance depending on a user's field of expertise. In order to clarify the use of the Library, this section provides the user with some key definitions and indications about what is found in this guidance document. Some of these definitions will be further explained later in the document within each specific section.

RISC-KIT project

The RISC-KIT EU project aims to deliver ready-to-use methods, tools and management approaches to reduce risk and improve resilience to coastal events, partly in the form of an open-source and free-ware RISC-KIT toolkit.

CRAF

The CRAF (Coastal Risk Assessment Framework) is one of the tools of the RISC-KIT toolkit. The CRAF can quickly assess present and future hotspot areas of coastal risk due to multi-hazards.

Risk

The risk is defined as the product of the probability of a hazard and its impacts (consequences).

Impacts

The consequences following a hazardous event affecting an area are mainly considered in the form of diverse direct and indirect losses, e.g. damages to buildings and loss of stocks, loss of life, loss of habitat, and disruption to services. The consequences can be calculated by considering the intensity of the hazard characteristics (e.g. flood depth, erosion, overwash), the exposure of receptors and their associated vulnerability. Ultimately, assessing these different impacts has the objective of understanding the potential overall consequences for the society. Following the Brundtland Commission[3] the European Commission promotes the sustainable development of our society. From a natural hazard perspective unsustainable development can be interpreted as the lack of ability of a system or a sub-system to return to a state similar to the one prevailing prior to disaster[4] as defined by the affected society. As much as possible, assessing the impact should reflect this lack of ability.

Exposure of receptors

Receptors within RISC-KIT mean the entities potentially at harm. For instance, a receptor can be a building, a person, a road, or a town and its population if considered at a different scale. But a receptor can also be a complex entity such as an economic activity, a community or an ecosystem. The exposure of receptors can be expressed by different orders. The loss assessment approach mainly focuses on the direct losses, i.e. only those receptors directly in contact with the hazard (e.g. flooded houses). The receptors directly impacted are then defined as being exposed at the first order. However they may also be indirectly impacted, i.e. by a higher order

[3] World Commission on Environment and Development (1987) Our common future. United Nations. 247p.

[4] Birkmann, J. (2006) Measuring vulnerability to natural hazards: towards disaster resilient societies. United Nation University Press. ISBN 92-808-1135-5. 400 p.

of losses also called indirect losses or induced losses[5] [6] [7]. This means that “impacts” may occur outside of an area directly impacted (e.g. power disruption if an electricity substation is damaged, traffic disruption if a road is blocked) or after the event (e.g. long-term health impacts).

Vulnerability

The vulnerability is at first defined in this document as the product of the sensitivity and the value of a receptor. The sensitivity (sometimes expressed as susceptibility) expresses the potential level of losses associated with the characteristics of the hazard. It can be expressed in different ways, e.g. as a percentage or as categories (low, medium, high). The sensitivity may also vary depending on the characteristics of the assets. For instance, a timber frame house may have a greater sensitivity than a concrete house for a similar flood. How to value the loss is not always straightforward. If a receptor has an economic value, this is often used as the best available information to assess value the potential loss and is thereby classified as a tangible loss. If not, the losses are classified as intangible and, then, the question remains for the stakeholders to decide and assign to the losses an economic value or an alternative, such as the level of disruption. For certain losses it may not be possible to express an economic/monetary value and, in such cases, only the sensitivity associated with a description of the losses could be used as the best available information.

The RISC-KIT project also aims to improve the assessment of the higher-order impacts and the resilience capacity of the coast exposed to extreme events. To do so the current definition of vulnerability is recognized as useful but limited to the assessment of the impact of the hazard. The system vulnerability should also be recognised[8]. This requires assessing or understanding how from one or more local impacts at a point in time the losses propagate through a system at a higher scale (meso, macro) and on a time period beyond the initial shock of an event. Expressing the systemic vulnerability cannot then be reduced to a single indicator and requires a more complex approach.

Indicator

A qualitative or quantitative estimation of vulnerability (state). Each indicator requires the consideration of both the hazard characteristics (input) and the type of receptor impacted (object).

[5] Messner, F., Penning-Rowsell, E., Green, C., Meyer, V., Tunstall, S. and Van der Veen, A. (2007) Evaluating flood damages: guidance and recommendations on principles and methods. EU Floodsite project N. GOCE-CT-2004-505420.

[6] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

[7] Rose, A. (2010) Economic principles, issues, and research priorities in hazard loss estimation. In modelling spatial and economic impacts of disasters – Springer edition. 13-36.

[8] Menoni, S., Molinari, D., Parker, D., Ballio, F. and Tapsell, S. (2010) Assessing multifaceted vulnerability and resilience in order to design risk-mitigation strategies. Natural hazards 52 (1). 28p.

Built Environment

The section on the Built Environment provides methods and indicators to assess the damages for man-made assets, i.e. buildings and their content and key infrastructure. The physical vulnerability is mainly expressed in the form of damage curves or in the form of a risk-matrix. The associated repaired or replacement cost or the market values are used to quantify the losses.

Flood depth-damage curves

A flood depth-damage curve, or damage function, is an indicator of the damage caused to a building or an asset at different flood depths. Damage curves are either expressed as an absolute or relative function. The absolute function presents the damage value to a particular asset in monetary terms either in relation to the building or per unit area. The relative function provides the susceptibility (sensitivity) expressed as a percentage of the total value of the asset.

Building Collapse matrix

The Building Collapse matrix indicates the potential degree of collapse (none, partial, or total) based on the characteristics of both the receptor (construction material) and the hazard (flood, erosion, wave impacts).

Erosion Vulnerability Indicator (ErVI)

Erosion Vulnerability indicates the probability of asset collapse and associated costs considering the distance between the asset and the shoreline during an event.

Population

The Population section provides methods and indicators to assess the potential impacts on the population. The section considers the potential threat on human life (Risk to Life) during an event and the vulnerability of different groups following an event (e.g. long-term health impact).

Social Vulnerability Indicator (SVI)

The SVI measures the relative vulnerability of different areas to long-term health and financial recovery from an event. This indicator is developed by considering the socio-economic characteristics of the areas exposed to certain hazards. Census data are commonly used to characterize the different populations.

Risk to Life Indicator

The Risk to Life indicator describes the potential injury or fatality during an event for a specific location based on the hazard, the location and the population characteristics.

Ecosystems

"An ecosystem is a dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit"[9]. The Ecosystems category considers a wide range of natural environments e.g. sand dunes, wetlands and crops.

[9] Millennium Ecosystems Assessment (2005) Ecosystem(s) http://www.greenfacts.org/glossary/tuv/vulnerability-ecosystems.htm (accessed 19.03.2015)

Ecosystem Vulnerability Indicator (EVI)

The concept of vulnerability for ecosystems includes the sensitivity of the ecosystem and its species and their resilience, in terms of their capacity to absorb the shocks while maintaining function[10]. The EVI estimates this lack of resilience by indicating the period of recovery for certain hazard thresholds.

Systemic

The Systemic section provides methods for assessing the vulnerability of a system (e.g. road, electricity and business). The method presents a step-by-step approach to gathering knowledge about the network and its assets to analyse the potential ripple effects and to, ultimately, define the systemic vulnerability under different conditions. The system is made up of a series of nodes, or assets, which receive input and/or produce output flows facilitated by a network. The network provides the support to these flows such as a railway line, a water distribution pipe, or a supply chain for business.

Disaster risk reduction (DRR) measures

Any measures (or groups of measures) taken to reduce the risk of a disaster. These can be implemented at many different scales (e.g. national, regional, communities and household) and by many different stakeholders (e.g. government agencies, businesses, community groups and individuals). Furthermore, measures may be implemented before (e.g. structural flood defences, spatial planning), during (evacuation, emergency response) or after an event (e.g. temporary alternative accommodation, financial recovery assistance). DRR measures may impact on all elements of risk; however in the context of the Coastal Vulnerability Indicator Library we are primarily concerned with those DRR measures that impact directly upon vulnerability.

[10] Millennium Ecosystems Assessment (2005) Vulnerability (in ecosystems) At: http://www.greenfacts.org/glossary/tuv/vulnerability-ecosystems.htm (accessed 19.03.2015)

3 How to use the Library

To start using the Library first open the Excel file "RISC-KIT_D.2.2_CVI_Library.xlsx"[11]. The opening introductory page gives access to this guidance document, and the Library by clicking the "Start" button (See Figure 3.1).

3.1 Library Structure

The Main Menu (Figure 3.2) allows the user to select their country of interest. However it should be stressed that for many countries and for some indicators no country-specific data are available. As such, a generic tab proposing the same approach is used within the Excel Library. At this stage of the project (end of Task 2.2) country-specific indicators are only available for a limited number of countries and for the indicators related to flood-damages curves (Built Environment), social impact (Population) and crops (Ecosystems). The development of new indicators based on the proposed methodologies, either by the case studies partners in WP5 ("Application at case study sites") or by future users following this project, will allow better population of the Library with country-specific data.

Figure 3.1: A snapshot of the introduction page

[11] Available on the RISC-KIT website: http://www.risckit.eu/np4/public_deliverables.html (D2.2)

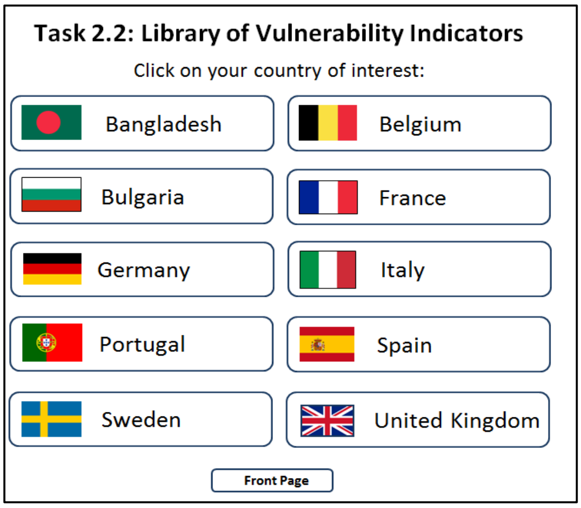


Figure 3.2: The Library is specifically tailored to each case study country

There are four categories within the Library: Built Environment, Population, Ecosystems and Systemic. There is also a section on Disaster-Risk Reduction (DRR) measures. The example in Figure 3.3 is for the UK, although all countries have the same structure. The four categories are broken down further into subcategories and these are explained below.

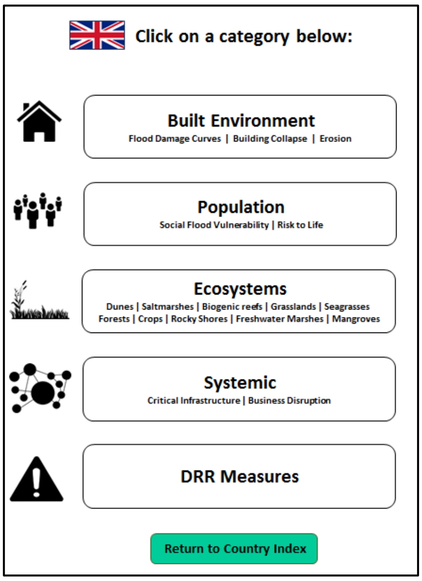


Figure 3.3: The main categories of indicators

Navigating around the Library is very intuitive, so step-by-step instructions on this aspect are unnecessary. But to help the user Figure 3.4 maps the general Library structure.

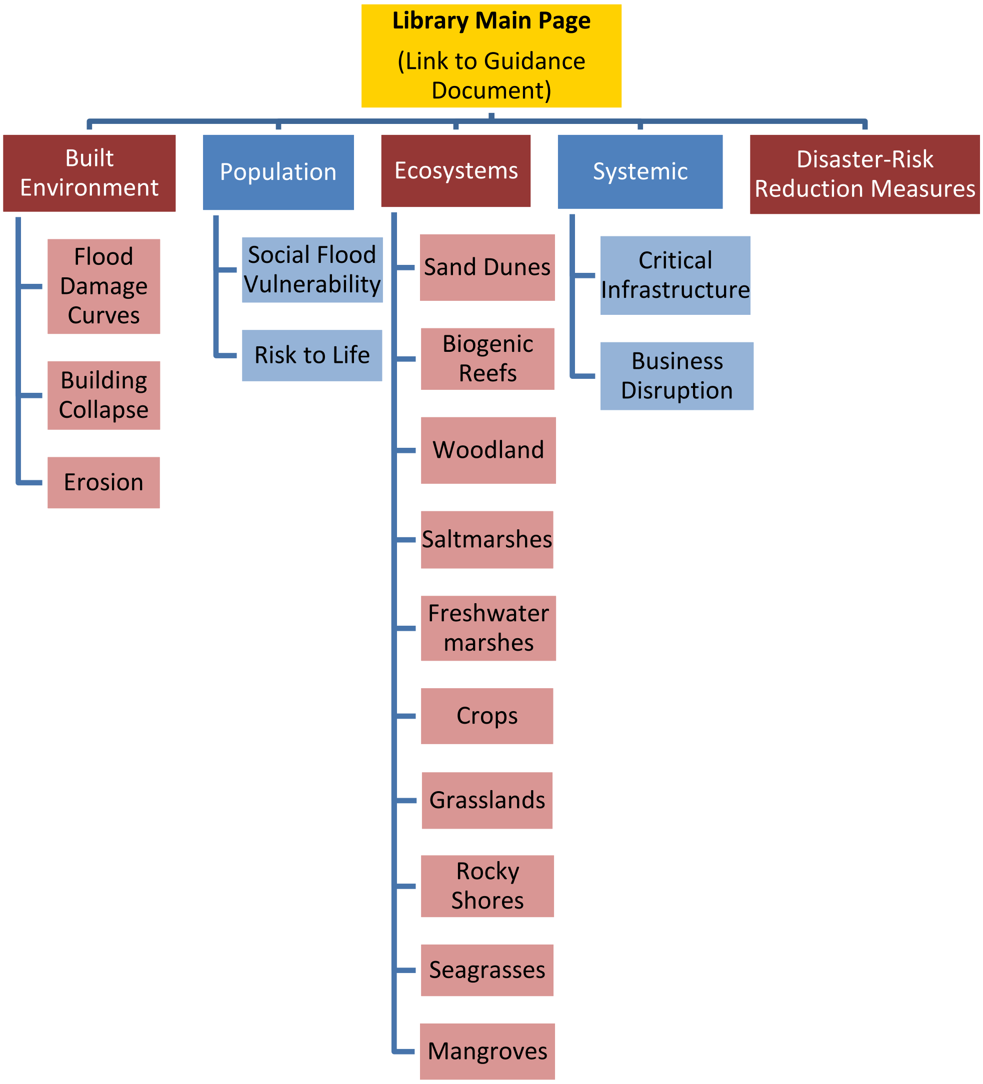


Figure 3.4: General Library structure

3.2 Methods and Options

The availability and the quality of indicators vary from one country to another. In certain cases the vulnerability indicators are based on detailed and thorough studies and might be recognized as official indicators for the specific country. In other cases the indicators result from international studies and, under certain conditions, might be transferable and applied in most case studies. But, often, indicators are non-existent in some places, are based on limited empirical evidence or lack validation. Where possible, such deficiencies have to be recognized and eliminated. It is, however, recognized that the required amount of resources and time might not be available. Within the Library a standardised series of methods (Method A and B) and options have been designed for most sections, if available, to respond to such concerns.

Return to Built Environment

Flood Damage Curves

Method A

Option 1

Buildings

Water depth	Houses	Furniture/Contents	Industry (area)	Industry (employees)
0.00	0.00	0.00	0.00	0.00
0.25	0.01	0.12	0.10	0.03
0.50	0.03	0.24	0.20	0.05
0.75	0.04	0.35	0.30	0.08
1.00	0.05	0.47	0.40	0.10
1.25	0.06	0.48	0.50	0.12
1.50	0.08	0.49	0.60	0.13
1.75	0.09	0.49	0.70	0.15
2.00	0.11	0.50	0.80	0.16
2.25	0.17	0.54	0.83	0.18
2.50	0.23	0.58	0.85	0.19
2.75	0.29	0.62	0.88	0.21
3.00	0.35	0.66	0.90	0.22
3.25	0.43	0.70	0.93	0.32
3.50	0.52	0.75	0.95	0.42

Figure 3.5: A snapshot of the Methods and Options used for flood depth-damage curves

Method A: Appropriate vulnerability indicators exist and are the most suitable for use.

Option 1: The indicator has been domestically produced and should be used as the best available indicator for the assessment (Figure 3.5 for an example). It is not always possible to include the datasets within the Library (primarily for licensing reasons), but a link to the source is provided for users to contact the relevant organisations in order to obtain access.

Option 2: Relevant indicators exist but have not been developed specifically for the country in question. The indicator is considered, however, to be of sufficient quality, reliability and appropriateness to be used.

Method B: Either the available indicator is not suitable for use or no indicator exists domestically or internationally. In this instance, an indicator has to be developed by the user.

Option 1: Use an existing indicator available elsewhere in the Library, which has been produced for another case, as a starting point for producing a new indicator for the country in question. Expert advice and judgment are required to select the most appropriate indicator available. This option should only be considered as a temporary solution until a new indicator is obtained following Method A or Method B - Option 2+. The level of confidence in the indicator should also to be reported within the assessment.

Option 2+: Produce a new and relevant indicator using methods obtained from a literature review. If more than one relevant method has been identified, multiple options are then provided. This may be labour and resource intensive but is necessary for a robust assessment.

4 Vulnerability Indicators for the Built Environment

The Built Environment category considers the direct damage to tangible assets. These include damage to buildings, including building collapse, and other assets, such as vehicles and caravans.

Damage to the built environment can occur in a variety of ways, such as from floodwaters entering properties and building structures suffering from wave impacts and erosion. Longer duration floods will usually lead to higher damages due to increased drying times and a higher clean-up cost. The presence of saltwater will also increase damage due to corrosion, oxidation and additional damage to paintwork and metallic finishes[12].

Most of the indictors have been identified at the national level and are usually an average for the entire country. For depth-damage curves (see below) this means that a national distribution of buildings is considered. When applied at the regional or local level, this national (average) distribution may not accurately represent the built environment where specific types of buildings may be prevalent. Although this will remain an issue to consider, due to a lack of region/case study-specific data, following the Methods outlined below should ensure that the most appropriate information available is applied. These methods predominantly describe property, but all methods and options are applicable to other assets, such as cars or caravans.

4.1 Flood Damage Curves

4.1.1 Introduction to flood damage curves

The assessment of direct, physical flood losses to the built environment is conducted in several countries and is commonly expressed as depth-damage functions or curves which provide the anticipated value or percentage of loss at a given flood depth inside the property. It should be mentioned here that a degree of uncertainty is inherent within all damage estimation data, and this needs to be considered by all users. Several studies[13] [14] [15] [16] [17] have demonstrated that the accuracy of models varies between countries and across different flood events. This may be due to a variety of factors, including uncertainties in the value and susceptibility of damage

[12] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

[13] Merz, B., Kreibich, H., Thieken, A. and Schmidtke, R. (2004) Estimation uncertainty of direct monetary flood damage to buildings. Natural Hazards and Earth System Science 4. 153-163.

[14] Merz, B., Kreibich, H., Shwarze, R. and Thieken, A. (2010) Review article: Assessment of economic flood damage. Natural Hazards and Earth System Sciences 10. 1697–1724.

[15] Bubeck, P., de Moel, H., Bouwer, L.M. and Aerts, J.C.J. (2011) How reliable are projections of future flood damage? Natural Hazards and Earth System Sciences 11 (12). 3293-3306.

[16] De Moel, H and Aerts, J. (2011) Effect of uncertainty in land use, damage models and inundation depth on flood damage estimates. Natural Hazards 58 (1). 407-425.

[17] Jongman, B., Kreibich, H., Apel, H., Barredo, J. I., Bates, P. D., Feyen, L., Gericke, A., Neal, J., Aerts, J.C.J.H. and Ward, P.J. (2012) Comparative flood damage model assessment: towards a European approach. Natural Hazards and Earth System Science 12 (12). 3733-3752.

components, a lack of consideration for the multitude of hazard characteristics (water velocity, the presence of contaminants etc.), the availability of historic event data in some countries and the level of existing knowledge on damage mechanisms.

Two functions are commonly used: the absolute or the relative function. The absolute function consists of establishing the damage function for a particular asset in monetary terms either in relation to the building or per unit area. The relative function provides the susceptibility (sensitivity) expressed as a percentage of the total value of the assets (Figure 4.1).

In each case the function can be established with a synthetic and/or an empirical approach. The empirical approach uses actual post-event damage assessment values. The synthetic, an ex-ante method, involves expert judgment (a "what if" analysis). See description of 'Method B' below for further details.

In order to obtain depth-damage functions for the case study countries, an extensive literature review has been conducted. Academic and private institutions have also been contacted, in addition to the discussions held with case study partners. Approximately half of the case study countries have nationally or locally produced data available for use for fluvial flooding, some of these albeit with restricted access. However, this leaves half of all the case study countries without national or local data from which to draw. To address this deficiency, and in order to ensure that all case studies have access to the most relevant data, a series of Methods and Options has been developed. It should be stressed that countries rarely develop specific coastal depth-damage curves for coastal flooding but simply applied an uplift factor to the fluvial curves.

Method A

Option 1

Buildings

Depth (cm)	**Residential** Flood Depth-Damages Curve per **property** (€)	
	Salt	Wave
0	2,047	2,047
60	54,570	56,449
90	59,332	61,197
120	65,063	66,608
150	70,526	72,436
180	76,748	78,996
210	82,066	84,682
240	87,046	89,998
270	98,357	101,749
300	103,556	107,225

Depth (cm)	**Non-Residential** (Commercial) Flood Depth-Damages Curve **per m²** (€)	
	Salt	Wave
0	64	69
60	995	1,085
90	1,338	1,453
120	1,747	1,888
150	2,163	2,341
180	2,482	2,637
210	2,776	2,864
240	2,906	2,973
270	3,077	3,130
300	3,128	3,184

Method A

Option 1

Buildings

Water depth	Houses	Furniture/Contents	Industry (area)	Industry (employees)
0.00	0.00	0.00	0.00	0.00
0.25	0.01	0.12	0.10	0.03
0.50	0.03	0.24	0.20	0.05
0.75	0.04	0.35	0.30	0.08
1.00	0.05	0.47	0.40	0.10
1.25	0.06	0.48	0.50	0.12
1.50	0.08	0.49	0.60	0.13
1.75	0.09	0.49	0.70	0.15
2.00	0.11	0.50	0.80	0.16
2.25	0.17	0.54	0.83	0.18
2.50	0.23	0.58	0.85	0.19
2.75	0.29	0.62	0.88	0.21
3.00	0.35	0.66	0.90	0.22

Figure 4.1: An example of an 'absolute' (left) and 'relative' depth-damage curve (right)

4.1.2 Method A: Using existing flood damage curves

Method A - Option 1

Where possible, national or regional indicators for the case study in question are provided and form the primary option when calculating likely flood damages to property. Indicators are available for Bangladesh, Belgium, France and the United Kingdom and depth-damage or susceptibility curves for these countries are listed in the Library. Some other countries, such as Germany, Italy and Spain, have produced datasets but due to licensing restrictions or their limited scope these are not currently provided in the Library. Sources for these data are given, and it is recommended that users contact the relevant individuals or organisations using the contact details provided in order to obtain permission for use or to find out if more extensive outputs are available.

Method A - Option 2

Where national or regional data remains outstanding (Bulgaria, Portugal and Sweden) or limited in scope (Italy and Spain), users should revert to Method A - Option 2: the damage data produced for the Joint Research Centre: Institute for Environment and Sustainability (JRC-IES).

JRC-IES, in partnership with HKV Consultants, has produced susceptibility curves and damage values for residential, commercial and industrial properties, and also for roads and agriculture[18]. This enables a damage assessment for various flood depths (between 0 and 6 metres) for fluvial (riverine) flooding in most European Union States. Data have been collected from various national studies in Belgium, Czech Republic, Denmark, France, Germany, Hungary, the Netherlands, Norway, Switzerland and the United Kingdom. An averaged susceptibility curve was then produced and can be applied for most EU member States (the EU was composed of 27 states at that time). A harmonisation process was also undertaken, based on national GDP to ensure that maximum damage values were as consistent as possible across the member states. This dataset thereby provides a good alternative to national indicators for those case studies where data remains unavailable or access is difficult. Due to restrictions on the publication of these data, the values cannot be stored within the Library. However, data can be requested by contacting the JRC-IES.

4.1.3 Method B: Developing flood damage curves

Where the indicators in Method A are unavailable or considered inappropriate for the case study site in question, Method B provides guidance on how to adapt existing indicators to reflect individual circumstances (Method B - Option 1), to create new indicators based on historic event information (Method B - Option 2) or to produce indicators using expert judgment (Method B – Option 3).

Method B - Option 1: Transferring indicators from one country to another

Depth-damage or susceptibility curves are available within the Library for four case study countries and three others have data available with permitted use. These curves can be used as a guide to inform the creation of new damage functions for buildings, caravans and vehicles in another country.

Where only susceptibility information is available (the percentage of maximum damage for each given flood depth), it will be necessary to identify the maximum value of the asset in question. These data may be held by local governments, insurers or can be obtained from discussions with stakeholders. It is common for the market value of assets to be employed for these purposes and this is often available online from relevant authorities and organisations.

The transferal of damage curves from one country to another is not a simple process and it is necessary to consider several aspects, including, but not limited to, the difference in the type, age and quality of assets between the two countries, the difference in household income and local prices. If there is significant variance between the two countries, for example the average

[18] Huizinga, H. J. (2007) Flood damage functions for EU member states. HKV Consultants, Implemented in the framework of the contract #382442-F1SC awarded by the European Commission – Joint Research Centre.

age of vehicles or the quality of construction materials used etc., it is wise to consider Option 2 or 3 below.

Method B - Option 2: Ex-post assessment

The *ex-post* or empirical approach uses knowledge and damage information obtained from local or regional historic flood events. Data are usually gathered from insurance companies, the local government or from surveys and interviews with flooded residents or business owners (See Figure 4.2).

Step i

As a minimum, the following data will need to be gathered: the flood depth and duration at a range of locations; the damage per household and per business (as separate figures, where possible); the type or size of each property (the ground floor size in m^2 for businesses) and their location *or* the total damages and the number of residential and non-residential properties affected and their location. Where accurate hazard characteristic data are not available (some local governments may hold this information) it may be necessary to model the flood in order to ascertain the associated flood depth and duration. This will require existing knowledge or expert guidance.

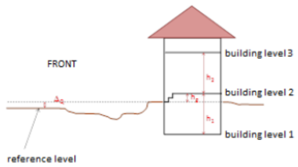
Step ii

When sufficient information has been gathered, for as many separate events as possible, it is then necessary to make a statistical analysis of the data. A damage figure (€) for each property or per square metre for businesses, due to the high variance in their characteristic (see Method B, Option 3, Step ii for more information) should be plotted alongside the actual or modelled flood depths. When a range of damage figures and depths has been ascertained, a damage curve for each property type or sector (residential/non-residential) can be constructed. Studies provide further guidance[19] [20].

[19] Prattenthaler, F., Amrusch, P. and Hasburg-Lothringen, C. (2010) Estimation of an absolute flood damage curve based on an Austrian case study under a dam breach scenario. Natural Hazards and Earth System Sciences, 10. 881-894.

[20] Pristrika, A., Tsakiris, G. and Nalbantis, I. (2014) Flood Depth-Damage Functions for Built Environment. Environmental Processes, December 2014, 1 (4). 553-572.

Table 3. Extract from the forms.

<table>
<tr><td colspan="3">SECTION 2: Building features</td></tr>
<tr><td>Aspect</td><td>Data</td><td>Notes</td></tr>
<tr><td>Building typology</td><td>☐ Detached house
☐ Apartment house/semi-detached house
Number of housing units |_|_|_|N°
Presence of attached buildings |_|_|_|N°
☐ Public building
Specify________________________</td><td></td></tr>
<tr><td>Period of construction</td><td>☐ Before 1945
☐ 1945–1991
☐ 1991–2007
☐ After 2007
☐ Renovation in the last 20 years</td><td></td></tr>
<tr><td>Building structure</td><td>☐ Masonry
☐ Mixed (masonry + concrete)
☐ Concrete
☐ Steel
☐ Wood
☐ Other ________________________</td><td></td></tr>
<tr><td>Surface</td><td>Width |_|_|_|_|m
Length |_|_|_|_|m</td><td></td></tr>
<tr><td>Number of storeys</td><td>|_|_| N°</td><td></td></tr>
<tr><td>Building elevation</td><td>

ΔQ |_|_|_|_|m
h_g |_|_|_|_|m
h_1 |_|_|_|_|m
h_2 |_|_|_|_|m</td><td></td></tr>
<tr><td>Attachment</td><td>☐ Photo of reference level
Description: ________________________</td><td></td></tr>
</table>

Figure 4.2: An example of a field survey form used to obtain empirical data from flooded residents[21]

Method B - Option 3: Ex-ante assessment

The *ex-ante* or synthetic approach to develop flood damage curve – as used in the UK, Belgium and France – takes a number of hazard factors and receptor characteristics into consideration, such as the flood depth inside the property, the number of storeys (floors), the type and quality of the building and usually the flood duration. Additional factors, such as flow velocity, sediment load and contamination may influence the severity and the extent of flood damage to buildings, but most flood damage models rarely include all of these additional factors[22]. This option requires existing knowledge or access to expert guidance.

Residential properties can be analysed as three separate components: the building fabric (walls, floors, plumbing etc.), the contents or inventory items (furniture, electrical goods, kitchen appliances etc.) and the cleaning and drying costs. For non-residential (commercial) properties, the type and vertical positioning of stock should also be considered.

[21] Molinari, D., Menoni, S., Aronica, G.T., Ballio, F., Berni, N., Pandolfo, C., Stelluti, M. and Minucci, G. (2014) Ex post damage assessment: an Italian experience. Nat. Hazards Earth Syst. Sci., 14, doi:10.5194/nhess-14-901-2014. 901-916.

[22] Pristrika, A., Tsakiris, G. and Nalbantis, I. (2014) Flood Depth-Damage Functions for Built Environment. Environmental Processes, December 2014, 1(4). 553-572.

As an example, a very detailed analysis, such as the Multi-Coloured Manual (MCM) approach[23], then breaks these three components down further into individual damageable items, such as flooring, a television, a washing machine etc. A susceptibility curve is then created for every item (see Table 4.1). The susceptibility curve estimates a percentage of damage to the item for each flood depth (in this case -30cm to +300cm, where the minus depths take into consideration damage to flooring from saturated ground). Two items have been highlighted in Table 4.1: 'pump out basements', where maximum damage occurs immediately at -30cm; and 'paint doors', where minor damage (10%) begins at a depth of 60cm. A maximum value is also calculated for each item based on the cost of repair or replacement, using secondary data sources (government statistics, insurance data etc.) and expert guidance. A final damage function (as contained within the Library) for each property or per square metre (for businesses) is then arrived at by building up a series of matrices for all of the items within the three damage components.

Table 4.1: A snapshot of a susceptibility curve for building fabric items (not all flood depths (in cm) shown)[24]

Description	-30	0	5	10	20	60	90	150	210	240	300
TIMBER GARAGE	0.00	0.00	0.00	0.02	0.05	0.15	0.18	0.50	0.95	1.00	1.00
PUMP OUT BASEMENT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CLEAN DRY TREAT SUB FLOOR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
EXTERNAL RENDER PAINT	0.00	0.00	0.00	0.00	0.05	0.12	0.14	0.18	0.24	0.26	0.35
REPAIR EXT DOOR & FRAME	0.00	0.00	0.00	0.00	0.02	0.12	0.14	0.20	0.40	0.60	0.00
REPLACE GLASS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.12	0.20
PAINT DOORS	0.00	0.00	0.00	0.00	0.00	0.10	0.15	0.20	0.30	0.40	0.80

In order to produce the flood depth-damage indicator, several steps should be followed:[25]

Step i

This is a complicated task which requires expert guidance. Contact professionals, such as building and quantity surveyors, builders, cleaning specialists and insurance loss adjustors etc.

Step ii

Consider the type of property (semi-detached house, flat, retail premises etc.), the age, number of storeys/floors and rooms and then obtain or create a ground-floor plan for each property type. Plans may be available from regional government offices, building surveyors or architects. This will make it easier to work out where inventory items are likely to be located (vertical height) and how many of each item is likely to be included (it can be expected that more rooms will equate to a higher number of damageable items). Non-residential properties have a larger variance than residential properties - consider, for example, the variance between a supermarket, factory, and hospital - and it is sensible to group them into similar types, such as offices, retail premises etc. Due to this variance, the ground floor size of non-residential

[23] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

[24] Ibid.

[25] Penning-Rowsell, E.C. and Chatterton, J. B. (1977) The Benefits of Flood Alleviation: A Manual of Assessment Techniques. Saxon House, Farnborough, England.

properties should be ascertained so that a final damage figure per square metre can be estimated (in Step v).

Step iii

Make a list of the items likely to be contained within each room or property type and the quantity of each. An example for the building fabric and inventory is provided in Table 4.2, and these should be adjusted to reflect the specific property characteristics. Depending on the time and resources available, a susceptibility curve can be created for each damageable item (as for the MCM approach[26], above) or an average curve for the building fabric and inventory. Both methods will require the assistance of experts in the field. A maximum damage value must then be obtained for each component based on their replacement or repair/refurbishment costs. Secondary data sources, such as store catalogues, or furniture websites can be employed here. The average charge for repairing or refurbishing items can be estimated by obtaining the average hourly charge for local contractors. Specialist items (such as antique furniture) will attract a higher damage value and this may need to be estimated where sources of data are absent. The average cost for drying and cleaning the property once floodwaters have subsided should also be calculated. This can be obtained from specialists and will usually be estimated per square metre of floor space. The estimate should include the cost of manpower (wages), the hiring of drying equipment (dehumidifiers) and the power required to operate this (cost of electricity per hour/day).

Step iv

Select a series of flood depths (metres) to analyse potential damages. These should reflect the local built environment, including the presence of any basements or cellars. The ground floor height should be treated as 0 cm and the use of 10cm increments is advised. To determine the maximum flood depth, consider the likely flood scenarios for the location, based on past events and future hazard predictions, and the how the built environment might be impacted. The maximum depth used in existing depth-damage curves ranges from 2-7 metres depending on the country.[27]

Step v

The final step is to compile the susceptibility curves into a matrix for all items/damage components/complete properties and the maximum damage figures in order to produce a series of depth-damage curves. It is then possible to produce average curves for each residential property type (semi-detached, flat etc.) or non-residential type (retail, office etc.) and then for the residential and retail sectors as a whole. The average curve should be weighted based on the local distribution of property types. For example, if 65% of local non-residential properties are retail establishments, this should be reflected in the final averaged curve.

[26] Penning-Rowsell, E. C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

[27] Jongman, B., Kreibich, H., Apel, H., Barredo, J.I., Bates, P. D., Feyen, L., Gericke, A., Neal, J., Aerts, J.C.J.H., and Ward, P.J. (2012) Comparative flood damage model assessment: towards a European approach. Nat. Hazards Earth Syst. Sci. (12). 3733-3752.

Due to the wide variance in non-residential properties (discussed above) it is useful to create damage values per square metre, which can then be applied regardless of the ground floor size of the building by multiplying the figure accordingly. Further guidance is available[28].

Table 4.2: Example components for building fabric and inventory items[29]

Building fabric
Fabric of building, main and outbuildings (e.g. garage, shed) including decorations
Electric light and power fittings but not appliances
Fitted kitchens
Plumbing installation and normal fittings
Heating installation, including firing unit
Power/gas supply to cooker but not the unit
Boundary walls, gates and fences, landscape constructions but not horticultural layout
Inventory
Domestic appliances, heating equipment and electrical appliances (e.g. hi-fi equipment, microwave oven)
Furniture and soft furnishings
Personal effects (including books, clothes, etc.)

[28] Messner, F., Penning-Rowsell, E., Green, C., Meyer, V., Tunstall, S. and van der Veen, A. (2006) Guidelines for Socio-Economic Flood Damage Evaluation. Floodsite Project Report T9-06-01. Available: http://www.floodsite.net/html/partner_area/project_docs/T9_06_01_Flood_damage_guidelines_D9_1_v1_0_p01.pdf (accessed 01.05.2015).

[29] Penning-Rowsell, E. C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

4.2 Building Collapse

4.2.1 Introduction to building collapse

In addition to the direct damages discussed previously, there will be some instances – particularly during coastal events involving wave forces - where the structural integrity of a building will be compromised, leading to a partial or total collapse. Table 4.3 provides an extensive list of flood actions. Of these, there are three main types of forces which floodwaters exert on a building: hydrostatic forces - associated with pressures of still water which increase with depth (outside of the property, in contrast to the depth-damage curves); hydrodynamic forces - associated with pressures due to the energy of moving water; and impact forces - associated with floating debris moved by water30, including from inside the property where heavy furniture may start to float and crash into walls because of wave actions[31].

Waves may impact significantly on the structure of certain assets particularly due to their repetitive loading[32]. Inspections to buildings in the aftermath of relatively recent hurricanes in the US found that wave loads had destroyed virtually all wood framed and unreinforced masonry walls below the wave crest elevation and only highly engineered structures were able to withstand the pressures created by breaking waves. It was found that these pressures can even be caused by wave heights of less than 0.9m[33]. The peak dynamic pressure can be as much as 15 to 18 times those calculated for non-breaking waves[34]. Overwash may also bring sediments and debris generating minor repairs and major cleaning operations to seafront structures in addition to an increase in the risk to life. Overtopping discharges may impact upon various coastal structures. Information, in the form of a qualitative estimation of impacts to traffic and structural safety (m^3/s per metre of structure), is available from USACE 2011[35].

Several studies[36 37 38 39 40] have been consulted in order to obtain indicators for use in the Library. There is a relative lack of data in this area of research and therefore options are

[30] Hawkesbury-Nepean Floodplain Management Steering Committee (HNFMSC) & New South Wales Department of Natural Resource (2006) Reducing Vulnerability of Buildings to Flood Damage: Guidance on Building in Flood Prone Areas. Hawkesbury-Nepean Floodplain Management Steering Committee, Sydney.

[31] Roos, W., Waarts, P. and Vrouwenvelder, A. (2003) Damage to Buildings. Delft Cluster Publication DC1-233-9.

[32] FEMA (2009) Recommended Residential Construction for Coastal Areas: Building on Strong and Safe Foundations. FEMA P-550, Second Edition, December 2009. Available at: http://www.fema.gov/media-Library/assets/documents/3972?id=1853 (accessed 15.01.2014).

[33] Ibid.

[34] USACE (1984) in Kelman, I. and Spence, R. (2004) An overview of flood actions on buildings. Engineering Geology, 73. 297-309.

[35] USACE (2011) Coastal Engineering Manual (CEM) Part V - Coastal Project Planning and Design, Chapter 5 Fundamentals of Design. See: http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=ARTICLES;101 (accessed 23.03.2015).

[36] Clausen, L.K. (1989) Potential dam failure: estimation of consequences, and implications for planning. Unpublished Master of Philosophy thesis at the School of Geography and Planning, Middlesex Polytechnic collaborating with Binnie and Partners. Redhill.

[37] Karvonen, T., Hepojoki, A., Huhta, H.-K. and Louhio, A. (2000) The use of physical models in dam-break analysis. RESCDAM Final Report, Helsinki University, 11 December 2000.

somewhat limited. Two of these studies (Karvonen et al., 2000[41] and Kelman, 2002[42]) were of particular interest to this project due to their scope and the type of built environment considered.

Table 4.3: Flood actions on buildings (Foerster et al., 2009 after Kelman and Spence, 2004)[43]

1. Hydrostatic actions: actions resulting from the water's presence • Lateral pressure from flood depth differential between the inside and outside of a building; • Capillary rise.
2. Hydrodynamic actions: actions resulting from the water's motion • Velocity: moving water flowing around a building imparting a hydrodynamic pressure • Velocity's localised effects, such as at corners; • Velocity: turbulence; • Waves changing hydrostatic pressure; • Waves breaking
3. Erosion actions: water moving soil, the water's boundary becomes dynamic and moves into adjacent solids
4. Buoyancy action: the buoyancy force
5. Debris actions: Actions from solids in the water • Static actions; • Dynamic actions; • Erosion actions;
6. Non-physical actions: • Chemical actions; • Nuclear actions; • Biological actions.

Kelman (2002) focussed on the physical vulnerability to flooding of coastal residences in Kingston-Upon-Hull and Canvey Island, UK. Surveys and empirical reserch identified the failure modes of most concern were caused by: the rate of rise of flood water inside a residence (establishing pressure differentials that could damage the residence), analysis of glass failure (focussing on large, low units in doors) and analysis of wall failure (focussing on cavity walls of unreinforced masonry)[44].

[38] Kelman, I. (2002) Physical Flood Vulnerability of Residential Properties in Coastal, Eastern England. PhD thesis, Cambridge University, UK. See: http://www.ilankelman.org/phd.html#downloads (accessed 23.03.2015).

[39] Kelman, I. and Spence, R. (2004). An overview of flood actions on buildings. Engineering Geology, 73. 297-309.

[40] Pristika, A. K. and Jonkman, N. (2009) Damage to Residential Buildings due to Flooding of New Orleans after Hurricane Katrina. Nat. Hazards, 54, DOI 10.1007/s11069-009-9476-y. 413-434.

[41] Karvonen, T., Hepojoki, A., Huhta, H.-K. and Louhio, A. (2000) The use of physical models in dam-break analysis. RESCDAM Final Report, Helsinki University, 11 December 2000.

[42] Kelman, I. (2002) Physical Flood Vulnerability of Residential Properties in Coastal, Eastern England. PhD thesis, Cambridge University, UK. See: http://www.ilankelman.org/phd.html#downloads (accessed 23.03.2015).

[43] Foerster, E., Krien, Y., Dandoulaki, M., Priest, S., Tapsell, S., Delmonaco, G., Margottini, C. and Bonadonna, C. (2009) Methodologies to assess vulnerability of structural systems. Del. 1.1.1., EU FP7 ENSURE Project.

[44] Foerster, E., Krien, Y., Dandoulaki, M., Priest, S., Tapsell, S., Delmonaco, G., Margottini, C. and Bonadonna, C. (2009) Methodologies to assess vulnerability of structural systems. Del. 1.1.1., EU FP7 ENSURE Project.

Further analysis of the Kelman matrices raised concerns; total building collapse (which Kelman terms 'DS5', see Figure 4.3) is assumed at all flood depths above 2 metres with zero velocity regardless of the property type or the number of floors. This is inconsistent with other literature reviewed (cited above) so the decision was taken to apply the Karvonen et al. (2000) indicator in the Library.

Table 12.3.12: Vulnerability Profile for Residences with A = 84 m^2 and j = 4

Maximum Flood Velocity	Maximum Flood Depth Differential					
	0.0 m	0.5 m	1.0 m	1.5 m	2.0 m	2.5 m +
0.0 m/s	DS0	DS2 Even if glass doors, DS3 unlikely	DS2 Even if glass doors, DS3 unlikely DS4 if weak wall panels	DS4	DS4	DS5
0.5 m/s	DS0	DS2 Even if glass doors, DS3 unlikely	DS2 Even if glass doors, DS3 unlikely DS4 if weak wall panels	DS4	DS4	DS5
1.0 m/s	DS0	DS2 Even if glass doors, DS3 unlikely	DS2 Even if glass doors, DS3 unlikely DS4 if weak wall panels	DS4	DS4	DS5
1.5 m/s	DS0	DS2 Even if glass doors, DS3 unlikely	DS2 Even if glass doors, DS3 unlikely DS4 if weak wall panels	DS4	DS4	DS5

Figure 4.3: An example of a matrix from Kelman (2002, 244), showing total building collapse ('DS5') at 2.5m flood depth and 0.0 m/s velocity[45]

The Karvonen et al. (2000) method is based on several previous studies[46] [47] [48] [49] [50] [51] and provides an assessment of flood vulnerability for the types of buildings common in Finland under various depths and velocities (Table 4.4). The work also uses physical models to investigate Manning's roughness and the direction and impacts of the flow between

[45] Kelman, I. (2002) Physical Flood Vulnerability of Residential Properties in Coastal, Eastern England. PhD thesis, Cambridge University, UK. See: http://www.ilankelman.org/phd.html#downloads

[46] Black, R.D. (1975) Flood Proofing Rural Residences: a 'Project Agnes' Report, Pennsylvania. Final Report prepared for the United States Department of Commerce, Economic Development Administration, Springfield, Virginia: National Technical Information Service, May 1975.

[47] Clausen, L. and Clark, P.B. (1990) The development of criteria for predicting dambreak flood damages using modelling of historical dam failures. In: White, W.R. (ed.) International Conference on River Flood Hydraulics, 1, John Wiley & Sons Ltd. Hydraulics Research Limited. 369-380.

[48] Lardieri, A. C. (1975) Flood proofing regulations for building codes. Journal of the Hydraulics Division, September 1975. 1156-1169.

[49] Lorenzen, R.T., Black, R.D. and Nieber, J.L. (1975) Design aspects of buildings for floodplain locations. ASAE Paper, 68th Annu Meet, Davis, ASAE St. Joseph, Mich Paper: 75-4037. 19 p.

[50] Sangrey, D.A., Murphy, P.J. and Nieber, J.K. (1975) Evaluating the Impact of Structurally Interrupted Flood Plain Flows. Technical Report No. 98, Project No. A-059-NY, Annual Allotment No. 14-31-0001-5032, submitted to The Office of Water Research and Technology, Washington, D.C., U.S.A:U.S. Department of the Interior.

[51] Smith, D.I. (1994) Flood Damage Estimation— A Review of Urban Stage-Damage Curves and Loss Functions. Water South Africa, 20 (3).

structures.[52] Although this study was focused on Finland, the dataset is applicable to other countries as the methodology focuses on building materials present at all case study sites (i.e. timber-framed, concrete, masonry and brick buildings) and represents the best available data. However, the dataset may not be appropriate for other building types. For example, in Bangladesh, it will be necessary to develop a new dataset using Method B for *kutcha* houses, constructed of straw, wood and bamboo, and for *pucca* houses made from bamboo, corrugated iron sheets, mud and brick[53]. This type of housing can sometimes be moved from an area at risk where sufficient warning permits such actions; this is discussed in the Disaster-Risk Reduction section of the Library.

Table 4.4: The Karvonen et al. (2000) damage matrix will form Method A for the Building Collapse section of the Library.[54]

House Type	Partial Damage	Total Damage
Wood-Framed: Unanchored	vd ≥ 2 m^2/s	vd ≥ 3 m^2/s
Wood-Framed: Anchored	vd ≥ 3 m^2/s	vd ≥ 7 m^2/s
Masonry, concrete and brick	v ≥ 2 m^2/s and vd ≥ 3 m^2/s	v ≥ 2 m^2/s and vd ≥ 7 m^2/s
Damage parameter vd (m^2/s) = flow velocity (v) multiplied by water depth (d)		

A study on residential damages in New Orleans post-Katrina[55] adapts the Clausen (1989) damage criterion[56] and is based on an empirical analysis of damages to a region of the city. This new approach (Figure 4.4) is very similar to the findings of Karvonen et al. (2000), discussed above, and provides further confidence in the choice of indicator to be used within the Library.

[52] Foerster, E., Krien, Y., Dandoulaki, M., Priest, S., Tapsell, S., Delmonaco, G., Margottini, C. and Bonadonna, C. (2009) Methodologies to assess vulnerability of structural systems. Del. 1.1.1., EU FP7 ENSURE Project.
[53] Islam, K.M.N. (2006) Impacts of Flood in Urban Bangladesh: Micro and Macro Level Analysis. A.H. Development Publishing House, Dhaka, Bangladesh.

[54] Karvonen, T., Hepojoki, A., Huhta, H.-K. and Louhio, A. (2000) The use of physical models in dam-break analysis. RESCDAM Final Report, Helsinki University, 11 December 2000.

[55] Pristika, A. K. and Jonkman, N. (2009) Damage to Residential Buildings due to Flooding of New Orleans after Hurricane Katrina. Nat. Hazards 54, DOI 10.1007/s11069-009-9476-y. 413-434.

[56] Clausen, L.K. (1989) Potential dam failure: estimation of consequences, and implications for planning. Unpublished Master of Philosophy thesis at the School of Geography and Planning, Middlesex Polytechnic collaborating with Binnie and Partners, Redhill, England.

- $dv < 3$ m²/s yields only "inundation damage"
- $3 \text{ m}^2/\text{s} \leq dv < 7 \text{ m}^2/\text{s}$ yields "partial damage"
- $dv \geq 7$ m²/s yields "total destruction"

Figure 4.4: The adjusted curve used for New Orleans[57]

4.2.2 Method A for building collapse

For the Building Collapse category, Method A is based on Karvonen et al. (2000)[58] - validated by Pristika et al.(2010)[59] – which is suitable for all case study sites as it considers timber-framed and brick/concrete buildings. The dataset has been adapted to make it comparable with other categories within the Library, using green for no collapse; orange for partial and red for total collapse (Figure 4.5).

Method A

<table>
<tr><th></th><th colspan="9">Depth-Velocity Product - vd (m²/s)</th></tr>
<tr><th>House Type</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>>7</th></tr>
<tr><td>Wood-Framed: Unanchored</td><td colspan="2">No Collapse</td><td>Partial Collapse</td><td colspan="6">Total Collapse</td></tr>
<tr><td>Wood-Framed: Anchored</td><td colspan="3">No Collapse</td><td colspan="4">Partial Collapse</td><td colspan="2">Total Collapse</td></tr>
<tr><td>Masonry, concrete and brick</td><td colspan="3">No Collapse</td><td colspan="4">Partial Collapse (if v is also ≥ 2 m²/s)</td><td colspan="2">Total Collapse (if v is also ≥ 2 m²/s)</td></tr>
</table>

After: Karvonen, T., Hepojoki, A., Huhta, H.-K. and Louhio, A. (2000) The use of physical models in dam-break analysis, RESCDAM Final Report, Helsinki University, 11 December 2000.

Figure 4.5: A snapshot of "Method A for Building Collapse" from the Library showing the adapted Karvonen et al. (2000) dataset.

Where partial damage occurs, refer to the flood depth-damage curves provided in the Library and also consider the additional costs incurred due to windows or doors being damaged. Consult local experts to obtain information on the likely costs involved.

For total collapse it will be more relevant to use rebuild costs as a proxy for the damage estimation. Insurance companies are likely to hold information on the average cost of rebuilding a property. An alternative approach is to use the local or regional market value of property as a guide. The average rebuild cost is likely to be slightly different than the market value, due to the fact that the value of the land on which the property rests is not considered in the rebuild costs.

[57] Pristika, A. K. and Jonkman, N. (2009) Damage to Residential Buildings due to Flooding of New Orleans after Hurricane Katrina. Nat. Hazards, 54, DOI 10.1007/s11069-009-9476-y. 413-434.

[58] Karvonen, T., Hepojoki, A., Huhta, H.-K. and Louhio, A. (2000) The use of physical models in dam-break analysis. RESCDAM Final Report, Helsinki University, 11 December 2000.

[59] Pristika, A. K. and Jonkman, N. (2009) Damage to Residential Buildings due to Flooding of New Orleans after Hurricane Katrina. Nat. Hazards, 54, DOI 10.1007/s11069-009-9476-y. 413-434.

In the UK case, rebuild costs are approximately 25% lower, on average, than the market value. Rebuild costs are the preferable option, where available.

Advancing coastal erosion may necessitate building relocation, and this option is discussed as a Disaster-Risk Reduction measure in relation to land use change (see Section 8).

4.2.3 Method B for building collapse

It may be possible to improve upon the generic Building Collapse indicator in Method A with local information from previous events or empirical research using modelling software and laboratory/field experiments. Data sources are limited, so existing knowledge or expert advice will be required for this.

Some studies[60] [61] [62] have been based on post-event analyses of the actual damage experienced by structures following flood events. The availability of historical hazard information is obviously crucial, as is evidence of structural collapse and also the absence of collapse, which will provide useful information about the resilience of the local built environment.

Previous event data is often held by regional governments, academic institutions and engineering companies. It may also be worth consulting local media sources, libraries and the internet. The following information should be obtained:

- Information on the hazard characteristics, such as water depth (m) and velocity (m/s). In addition, the presence of any contaminants (saltwater, sewage, pollutants, heavy metals etc.) or debris (trees, vehicles, boats etc) should be ascertained, where possible. If information on the hazard characteristics is not available, it may be necessary to conduct a modelling exercise to determine this ex-post. In recent times it has become common for members of the public to record flood events with cameras and mobile phones, and this footage may have been uploaded to photo or video sharing website such as Flickr and YouTube. This is becoming a useful resource for researchers, and can be consulted to assist with the calibration of past events. A cautious approach must be taken when validating the authenticity and location of the material;
- Information on the receptor characteristics: building type (residential or non-residential; semi-detached house, flat etc.); building size (the ground floor size m^2); the type of construction materials used (timber, brick, concrete etc.); number of storeys/floors; distance between structures; the building threshold (the height at which water will enter the property); and presence of any resistance or resilience measures (flood proofing, flood barriers etc.) – see also Section 8.

Once this information has been collected, it should be possible to validate or improve the existing building collapse indicator by changing the depth-velocity product to reflect observed

[60] Lorenzen, R.T., Black, R.D. and Nieber, J.L. (1975) Design aspects of buildings for floodplain locations. ASAE Paper, 68th Annu Meet, Davis, ASAE St. Joseph, Mich Paper: 75-4037. 19 p.

[61] Sangrey, D.A., Murphy, P.J. and Nieber, J.K. (1975) Evaluating the Impact of Structurally Interrupted Flood Plain Flows. Technical Report No. 98, Project No. A-059-NY, Annual Allotment No. 14-31-0001-5032, submitted to The Office of Water Research and Technology, Washington, D.C., U.S.A:U.S. Department of the Interior.

[62] Clausen, L. and Clark, P.B. (1990) The development of criteria for predicting dambreak flood damages using modelling of historical dam failures. In: White, W.R. (ed.) International Conference on River Flood Hydraulics, John Wiley & Sons Ltd, Hydraulics Research Limited. 369-380.

impacts to the local built environment. This new indicator will then effectively revert to Method A to be used at the case study site.

With existing knowledge or expert guidance and access to specialist facilities, it is possible to conduct laboratory experiments in wave tanks, flumes (Figure 4.6) or with field-based studies (Figure 4.7) using sensors and statistical analysis software in order to analyse how forces impact upon different types of structures and materials. Replica models of buildings are used for this at a much reduced scale. Limited guidance is available[63] [64] [65] so advice from experts is a crucial requirement. Again, once gathered this information should be used to improve the existing depth-velocity product within the indicator to better represent the local built environment.

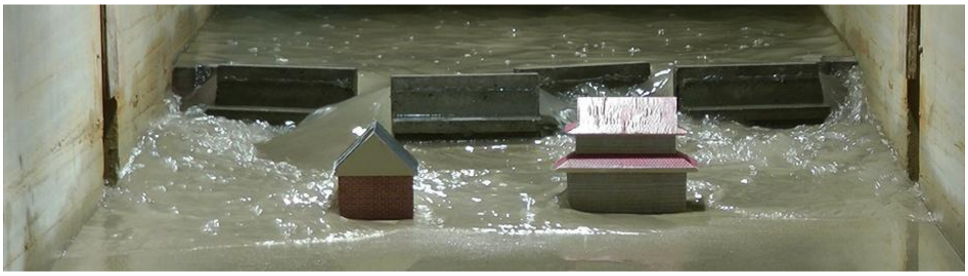


Figure 4.6: HR Wallingford's indoor Tsunami Simulator[66]

Figure 4.7: Controlled outdoor testing conditions[67]

---

[63] Black, R.D. (1975) Flood Proofing Rural Residences: a 'Project Agnes' Report, Pennsylvania. Final Report prepared for the United States Department of Commerce, Economic Development Administration. Springfield, Virginia: National Technical Information Service, May 1975.

[64] Duarte, R.B. (1998), The Design of Unreinforced Brickwork Panels with Openings under Lateral Pressure. Masonry International, 11 (3). 97-101.

[65] Escarameia, M., Karanxha, A. and Tagg, A. (2007) Quantifying the flood resilience properties of walls in typical UK dwellings. Building Services Engineering Research and Technology, 28 (3). 249-263.

[66] HR Wallingford Tsunami simulator (first generation): http://www.hrwallingford.com/facilities/tsunami-simulator-1st-generation (Accessed 23.02.15)

[67] Aglan, H., Wendt, R., Livengood, S. (2004) Field testing of energy-efficient flood-damage resistant residential envelope systems. Summary Report, ORNL/TM-2005/34 Oak Ridge National Laboratories Report, Oak Ridge, Tennessee, USA: ORNL. Available from: http://www.osti.gov/scitech/biblio/885989 (accessed 20.02.15).

4.3 Erosion Vulnerability Indicator

4.3.1 Introduction to Erosion

The management of coastal erosion, especially long-term erosion, is described in many manuals, including methodologies for assessing the potential coastal vulnerability to erosion. The assessment is mainly based on combining two components: the potential shoreline change over a long period of time and the distance of natural island barriers, protection (e.g. dikes, seawalls etc.) and assets to that shoreline[68] [69] [70] [71] [72] [73]. Economic valuation of such risk exists for long-term planning and involves assessing the annual value and the lifespan of the asset at risk[74] [75]; the lifespan being the function of the yearly erosion rate. However, short-term shoreline fluctuations following extreme storm impacts of duration of as little as a couple of hours[76] [77] may be equivalent to decades of long-term erosion and can suddenly endanger land use and associated activities (beach use, road, train services). In some cases the impact is directly related to the erosion process as the foundations of assets may be undermined leading to instability or structural collapse. In such cases the loss of the asset is considered as total and as irremediable. The question is, often, to define the value of the asset and, eventually, the impact on associated activities. If available, the market value of the asset represents the loss. If the asset has an associated business value and this is not included in the market value, it should also be included in the loss. In certain cases exceptional measures might be taken to rebuild both the asset and the foundation and, therefore, in these situations only the costs of repair associated with the disruption should be considered. If the asset is of sufficient importance, and defined as such through the Systemic vulnerability assessment, the potential knock-on effect on the short

[68] Cechet, B., Taylor, P., Griffin, C. and Hazelwood, M. (2011) Australia's coastline: adapting to climate change – assessing infrastructure vulnerability to rising sea-levels. AUSGEO news 101. 9p.

[69] Contreras, D. and Kienberger, S. (2011) Deliverable D4.2: handbook of vulnerability assessment in Europe. MOVE Collaborative Project – GRANT AGREEMENT No. 211590. 129p.

[70] Ciavola, P., Ferreira, O., Haerens, P., Van Koningsveld, M. and Armaroli, C. (2011) Storm impacts along the European coastlines - Part2: lessons learned from the MICORE project. Environmental Science and Policy 14. 924-933.

[71] Universitat Autonoma de Barcelona and Geographic Information Management NV (2002) Coastal Erosion – evaluation of the needs for action. EUROSION - Directorate General Environment European Commission project. 49 p.

[72] Penning-Rowsell, E.C., Priest, S., Parker, D.J., Morris, J., Tunstall, S., Viavattene, C. and Owen, D. (2013) Flood and coastal erosion risk management: A manual for economic appraisal. Routledge, London.

[73] The Heinz Center (2000). Evaluation of erosion hazards. Federal Emergency Management Agency.

[74] Penning-Rowsell, E.C., Priest, S., Parker, D.J., Morris, J., Tunstall, S., Viavattene, C. and Owen, D. (2013) Flood and coastal erosion risk management: A manual for economic appraisal. Routledge, London.

[75] The Heinz Center (2000). Evaluation of erosion hazards. Federal Emergency Management Agency.

[76] Ferreira, O., Garcia, T., Matias, A., Taborda, R. and Dias, J.A. (2006) Integrated method for representation of set-back lines for coastal erosion hazards at sandy shores. Continental Shelf Research 26 (9). 1030-1044.

[77] Federal Emergency Management Agency (2011) Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas (4th ed.).

and long-term should be considered (see Section 7: Systemic Vulnerability Indicators). The sudden change of the shoreline may also have an impact on the value of assets situated nearby. For instance the Heinz Center (2000)[78] indicates that the property value may change as a function of the expected number of years the shoreline will take to reach the property, but that such change may be variable from one region to another. Such studies remain outside the scope of this project. In some instances, building relocation may be a necessary mitigation measure and this is considered in terms of land use change in Section 8: Disaster-Risk Reduction measures.

The destruction of natural island barriers or protection often leads to an increased exposure to other hazards such as floods, wave impacts, sedimentation and salinization[79]. Consequently, it is essential not only to consider the distance between the assets and the shoreline but also the presence of natural barriers and protection as well as the elevation of the assets behind them. The potential vulnerability of areas to flooding which are suddenly unprotected by eroded barriers is however not considered here. The reader should instead refer to the other sections of this guidance document on flood vulnerability. In addition, the progression of the waterline, the run-up level accompanying the shoreline retreat needs also to be considered as an indirect impact of the erosion (i.e. direct impact of waves and of overwash by run-up to assets). This question is discussed in Section 4.2: Building Collapse.

Figure 4.8: Evacuation of a building threatened by erosion[80]

[78] The Heinz Center (2000). Evaluation of erosion hazards. Federal Emergency Management Agency.

[79] Federal Emergency Management Agency (2011). Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas (4th ed.).

[80] Image source: Laurent Theillet/Sud-Ouest (2014). Soulac(33): evacuation imminente des habitants de l'immeuble le Signal, menace par l'ocean. http://www.sudouest.fr/2014/01/23/soulac-33-evacuation-

4.3.2 Erosion Vulnerability Indicator

The proposed Erosion Vulnerability Indicator refers only to the erosion process leading to instability or structural collapse as foundations are undermined due to transient storm shoreline change. As introduced previously the Erosion Vulnerability Indicator is therefore based on the distance between the shoreline and the assets. Despite this being a standard approach, it remains difficult to define generic indicator values as these will depend on the nature of the soil, type of assets and foundations, existing regulations in terms of safety and the existence of preventive measures. Therefore the development of the indicator should be site specific and is proposed as a Method B in the Library.

The Erosion Vulnerability Indicator (ErVI) is related to the direct impact of erosion leading to the retreat of the shoreline and the potential loss of assets (e.g. barriers, properties, roads,) and utilises the method developed by Ciavola et al. (2011)[81] in the frame of the FP7 EU project MICORE for shoreline retreat assessment (herein called Sr-A). The Sr-A simply measures the distance (in metres) between the expected computed retreat position of the shoreline and the considered asset. Three situations need to be considered: first, if the distance Sr-A is negative or close to 0, the foundation of the asset (at least in the case of a soft shoreline) is undermined and the asset can then be considered as lost. However, even if the Sr-A has a positive value for security and preventive reasons the use of the asset might be temporally stopped (e.g. property evacuation, a reduction or suspension of traffic) before and during the event; or disruption could continue after the event to allow assessment of the foundations.

In order to assess the potential vulnerability of an asset to direct erosion impact, it is therefore necessary to define the following minimum distances between the asset and the shoreline in metres (Figure 4.9) [82]:

- Tp (Preventive Threshold) = Below this threshold activities will be disrupted before and during the event for safety reasons;
- Tpm (Post Monitoring Threshold) = Below this threshold activities will also be affected by the need for monitoring in the aftermath of an event;
- Tl (Loss Threshold) = Below this threshold the asset will partially or totally collapse.

imminente-des-habitants-de-l-immeuble-le-signal-menace-par-l-ocean-1438820-3193.php (accessed 23.02.2015)

[81] Ciavola, P., Ferreira, O., Haerens, P., Van Koningsveld, M. and Armaroli, C. (2011) Storm impacts along the European coastlines - Part2: lessons learned from the MICORE project. Environmental Science and Policy 14. 924-933.

[82] Tp, Tpm and Tl were for instance defined as 9m, 6m and 3m for a specific case study in the MICORE project. In: International Marine and Dredging Consultants (2011). Deliverable 5.1 – GIS based hazard maps. MICORE EU FP7 project N202798. P14. (restricted report)

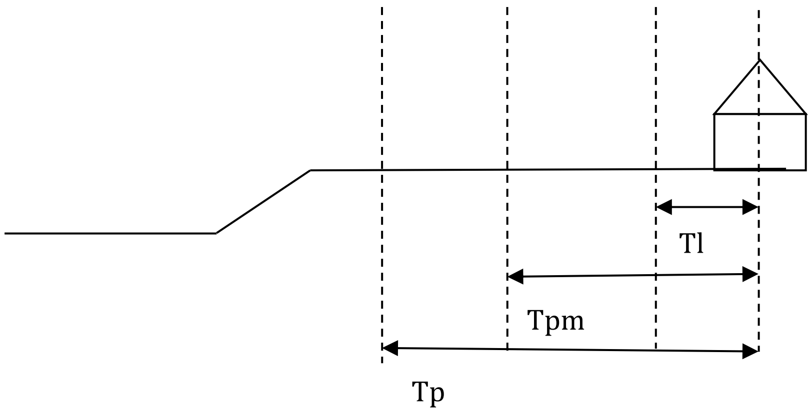


Figure 4.9: Distance Thresholds used to define the Erosion Vulnerability Indicator

The Erosion Vulnerability Indicator (ErVI) can then be derived once the Sr-A is calculated using Table 4.5. If Sr-A is greater than the preventive threshold, a risk of collapse due to erosion is not considered for the asset. However if Sr-A is less than Tp (Preventive Threshold), then an evacuation will be enforced for safety reasons, before and during the event, and the disruption of the activities should be considered as a loss. If the distance is less than Tpm, the shoreline is getting closer to the building. It represents a medium risk of building collapse. In such cases, the disruption of the activities continues after the event to carry out the required monitoring of the asset and its foundation. If Sr-A is lower than Tl, then the probability of collapsing is high. The total loss of the asset (e.g. its market value) and the associated activities should be considered (or its temporal loss and the cost of rebuilding if exceptional measures are taken). In each case the partial or temporal loss of the considered asset or services is likely to lead to further indirect effects (e.g. the knock-on effects to delivery of critical services or economic activities, increased exposure to other hazards such as floods, wave impacts, sedimentation), and additional vulnerability assessments will need to be carried out. This method could be equally applied for other receptors such as beaches, agricultural land.

Table 4.5: Erosion Vulnerability Indicator

	Sr-A >= Tp	Tp <= Sr-A <=Tpm	Tpm <= Sr-A <= Tl	Tl <= Sr-A
ErVI	None	Low probability of asset collapse: Disruption caused by preventive evacuation before and during the event	Medium probability of asset collapse: Disruption caused by preventive evacuation as well as during and post event checking/monitoring by civil protection and coastal management institutions	High probability of collapse: High disruption and total loss of asset

5 Vulnerability Indicators for the population

The Population category in the Library contains indicators which aim to measure the impacts from a flood event on people. Here, two main indicators are included: A Social Vulnerability indicator which measures the relative vulnerability of the population to long term health and financial recovery from coastal events, and Risk to life, an indicator of potential injury or fatality during an event for a specific location.

5.1 Social Vulnerability

5.1.1 Introduction to Social Vulnerability Indicators

Vulnerability is a contested term that has evolved in different disciplines and has been used for many decades now, and although there is no single precise definition[83], several attempts have been made to define it[84] [85] [86] [87] [88] [89]. Within the sphere of natural hazard studies, the term was first used to refer to the physical susceptibility of built structures, and has now expanded beyond this and assessments of vulnerability to include economic, social and environmental aspects of a population at risk.[90] The Social Vulnerability Indicator within the Library measures the relative vulnerability of different populations to long-term health impact and financial impact from an event. For this purpose we use the definition by Cutter et al. (2013) "Social vulnerability describes those characteristics of the population that lead to differential impacts of natural hazards"[91]. The objective, here, is to identify appropriate methodologies to calculate this indicator for the different participant countries.

---

[83] Fekete, A., Hufschmidt, G. and Kruse, S. (2014) Benefits and challenges of resilience and vulnerability for disaster risk management. International Journal of Disaster Risk Science, 5. 3-20.

[84] Birkmann, J. (2006) Measuring vulnerability to natural hazards: Towards disaster resilient societies. United Nations University Press: New York.

[85] Birkmann, J. (2007) Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. Environmental Hazards, 7. 20-31.

[86] Kuhlicke, C., Scolobig, A., Tapsell, S., Steinfuhrer, A. and De Marchi, B. (2011) Contextualizing social vulnerability: findings from case studies across Europe. Nat. Hazards 58. 789–810.

[87] Balica, S.F., Douben, N., Wright, N.G. (2009) Flood vulnerability indices at varying spatial scales. Water Science Technol. 60(10). 2571-2580.

[88] Vogel, C., Moserb, S.C., Kaspersonc, R.E. and Dabelko, G.D. (2007) Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. Global Environmental Change 17. 349–364

[89] Granger, K., Jones, T., Leiba, M. and Scott, G. (1999) Community Risk in Cairns: a Provisional Multi-Hazard Risk Assessment. AGSO Cities Project Report Number 1, Canberra: Australian Geological Survey Organisation.

[90] Birkmann, J. (2007) Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. Environmental Hazards, 7. 20-31.

[91] Cutter, S.L., Emrich, C.T., Morath, D.P. and Dunning, C.M. (2013) Integrating social vulnerability into federal flood risk management planning. Flood Risk Management (6). 332–344

The Social Vulnerability Indicator helps understand why the impacts on a certain population will differ from another population when exposed to an event. Floods can impact on households and communities in different ways (e.g. short and long-term psychological and physical impacts, higher deprivation and family disruption) and will depend upon the socio-economic characteristics of those affected, the characteristics of the flood and the levels of exposure. Social inequalities, and the root causes of these, are not necessarily social vulnerabilities leading to disaster, only leading to unequal social conditions generally. However, it is these inequalities that may also affect peoples' capacities to respond and recover from hazardous events. Understanding social vulnerability is critical to conducting proper risk management strategies, allowing stakeholders and decision-makers to identify areas where action is more needed.

"Vulnerability indices have been developed as a rapid and consistent method for characterising the relative vulnerability of different areas"[92] using either a descriptive scale from low to high vulnerability or a numeric one from 0 to 5, for example. While some of these only assess the physical characteristics of the area, the more complex ones add aspects of economic and social characteristics. This part of the Library concentrates on the social, economic and financial aspects of populations; hence we only need to consider indicators which use characteristics of this nature. Certain authors use the term index rather than indicator. In such cases the terms index and indices are used in this document to refer to their approaches.

Many indices exist for measuring vulnerability and social vulnerability in particular and each of these includes their own set of variables. Increasingly, practitioners seem to be progressing from talking about 'vulnerable groups' to seeing vulnerability as highly dependent on the specific local context[93]. For example, Kuhlicke et al. (2011) in a study comparing social vulnerability to floods in three European countries (Germany, UK and Italy) found that it was not possible to identify a common set of socio-economic–demographic indicators to explain the social vulnerability of groups and/or individuals for all phases of flood events.[94] Vulnerability was found to be a product of specific environmental, spatial, socio-economic and demographic contexts in the three countries. Because of the nature of this project which involves many countries with different contexts, the Library therefore does not have only one indicator to assess social vulnerability but proposes a methodology to assess social vulnerability taking into account the specific context of the population that needs to be assessed. The proposed methodology allows the user to choose between different options in order to assess vulnerability in the most appropriate way possible.

The methodology for applying a Social Vulnerability Indicator follows a similar approach as the other categories of this Library. Method A proposes the use of existing indicators, and Method B includes a methodology to create bespoke indicators. Options 1 and 2 within Method B differ from the methods used for the other categories in the Library, as they are specific to the Social Vulnerability Indicator. Options 1 and 2 also include five steps which should be followed. The following sections describe and explain the different methods and options. Figure 5.1

[92] Balica, S.F., Wright, N.G. and van der Meulen, F. (2012) A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Natural Hazards 64. 73–105.

[93] Zsamboky, M., Fernández-Bilbao, A., Smith D.J. and Knight, J. (2011) Impacts of Climate Change on Disadvantaged UK Coastal Communities. Joseph Rowntree Foundation.

[94] Kuhlicke, C., Scolobig, A., Tapsell, S., Steinfuhrer, A. and De Marchi, B. (2011) Contextualizing social vulnerability: findings from case studies across Europe. Nat Hazards 58. 789–810.

synthetizes with a schematic view the whole methodology proposed for calculating social flood vulnerability.

The outputs of the Social Vulnerability Indicator are scaled from “very low” to “very high” for each unit of analysis (e.g. neighbourhoods, municipalities, or even smaller divisions). Results can be also represented in a map, as shown in Figure 5.2 for North Norfolk, UK.

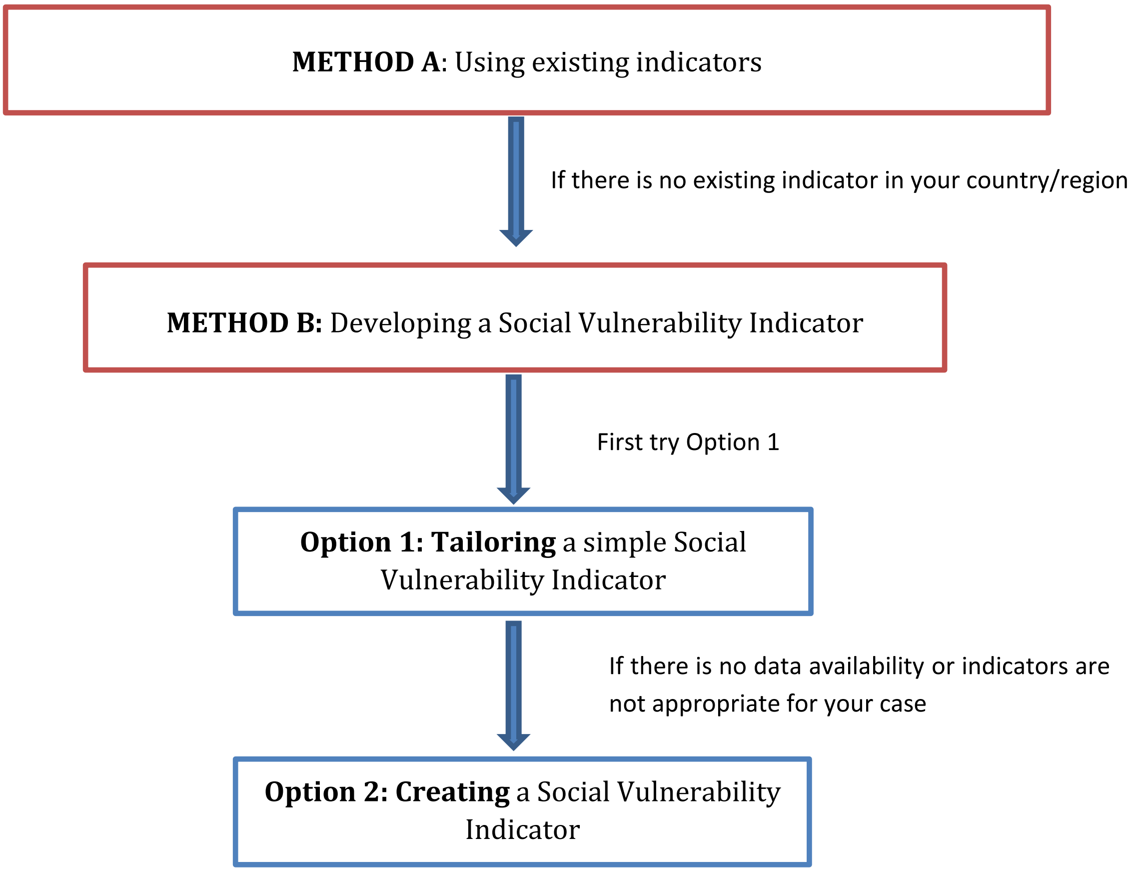


Figure 5.1: Flowchart of the methodologies for Social Vulnerability

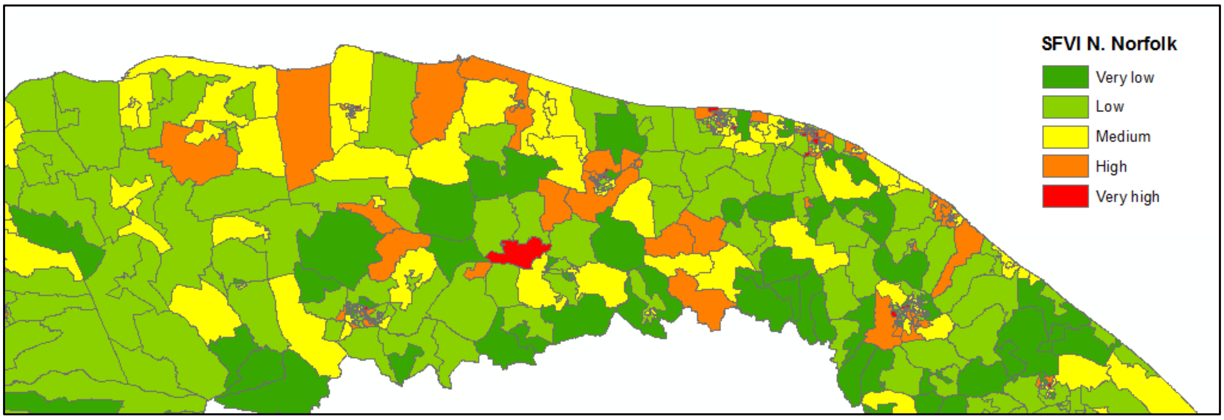


Figure 5.2: SFVI by Output Areas. North Norfolk (England)

5.1.2 Method A: Using existing indicators

The first proposed method is to use an existing indicator which has already been developed for the country or region. This means results are readily available. Many indicators have been developed in order to measure and identify groups vulnerable to flooding or other impacts [95] [96] [97], and each of these uses different variables for measuring vulnerability (e.g. elderly, level of education, etc.). As mentioned earlier the decision for selecting a certain variable depends upon the specific contexts involved and the problem which needs to be assessed. A specific Social Vulnerability Indicator has only been identified for the UK, Bangladesh and Germany[98] within the RISC-KIT partners (See Appendix C for details on the German and Bangladeshi indices). For example, the Social Flood Vulnerability Index (SFVI) was developed for England and Wales in order to identify communities vulnerable to adverse health effects from fluvial floods[99]. However, Method A encourages the user to see whether there is a similar indicator for Social Vulnerability that they consider to be applicable to their location.

A literature review of existing international indicators revealed a range of different approaches (which had been both applied to floods, coasts and other hazards) and these are listed in Appendix A along with the scale at which they were applied and the variables selected to build the indicator. It should be highlighted here that some of these indicators consider also flood hazard exposure as variables (e.g. the Local Flood Vulnerability Index for Spain considers historical flood marks), and for this methodology these variables will not be considered. It is also important to mention here that none of these indicators addresses vulnerability to extreme events. It is also useful for the users to know whether an indicator has been validated or tested, or not. The tables in Appendix A also provide this information for most of the cases.

Non-flood specific indicators similar to the Index of Multiple Deprivation (IMD) [100] in England and Wales might also be available and applicable for participant countries. The purpose of the English IMD (2010) is to identify small areas of England which are experiencing multiple aspects of deprivation. The IMD is nowadays used by the Environment Agency[101] to identify hot spot areas where the population is more vulnerable to floods (See the Population category for

---

[95] Cutter, S.L., Boruff, B.J. and Shirley, W.L. (2003) Social vulnerability to environmental hazards. Soc Sci Q, 84(1). 242–261.

[96] Weichselgartner, J. and Bertens, J. (2002) Natural disaster reduction in Europe: a Don Quixotic project in the face of a changing world? In Brebbia, C.A. (ed.) Risk Analysis III. WIP Press, Southampton. 233-242.

[97] Balica, S.F., Wright, N.G. and van der Meulen, F. (2012) A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Natural Hazards 64. 73–105.

[98] Fekete, A. (2010) Assessment of Social Vulnerability for River-Floods in Germany. Doctoral thesis,

University of Bonn, Germany.

[99] Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. Phil. Trans. R. Soc. Lond. 360. 1511-1525.

[100] CLG (2010) English Indices of Deprivation 2010. Guidance document. Department of Communities and Local Government. At: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6222/1871538.pdf (accessed 23.01.2015)

[101] The Environment Agency is the governmental institution which has the duty to manage flooding for rivers, the sea and reservoirs, as well as adopting the strategic overview role for all sources of flooding in England.

the UK in the Library to obtain the data). Although not specifically addressing vulnerability to flooding, these general deprivation indices might be suitable for application as a Social Vulnerability Indicator. Although less specific, they have the advantage of being already developed and in many cases calculated, mapped and the data available for application. Case study owners are therefore encouraged to identify whether a similar deprivation indicator is also available for their area.

If a non-specific indicator is to be applied in the case study area; there are some aspects that need to be taken into consideration:

- Is it culturally and regionally appropriate? Some indicators developed at a national scale might not reflect important aspects at a regional or local scale.
- Is it validated? Can you validate it? How confident are you in the results?
- Does it have a sufficiently high level of disaggregation to permit an assessment of the differences within any area? For instance the census output areas in England[102] allow a detailed analysis of the North Norfolk case study (see the map in Figure 5.2).

It is recommended that these potential limitations are recorded and noted within an explanation of how they may impact upon the outcomes of the case study assessment.

5.1.3 Method B: Developing new Social Vulnerability Indicators

If there is no existing Social Vulnerability Indicator (or a lack of an applicable one), then there is a need for developing a specific indicator. Method B proposes tailoring an existing indicator (we propose the SFVI used in England) in Method B - Option 1 or creating a new one in Method B - Option 2.

Method B - Option 1: Tailoring an existing simple Social Vulnerability Indicator

A simple Social Vulnerability indicator can be applied using the methodology developed in England and Wales by the Flood Hazard Research Centre[103]. The aim of the SFVI is to identify or predict areas and populations that are likely to be more severely affected from flooding in terms of long term impacts on health and financial recovery. In order to apply this indicator follow *steps i* to *v*.

Step i: Consideration of variables

The Social Flood Vulnerability Index (SFVI) for England is a composite additive index based on four characteristics (financial deprivation, age, family structure and health). Each characteristic is represented by a number of variables (See Table 5.1) (Appendix B - Table 1 - explains the rationales for the selection of each of the indicators). The SFVI is a good example as it was designed for high levels of data disaggregation, being suitable for the RISC-KIT 100 km regional scale. The SFVI can be used as a first step for the identification of hot spot areas where medium and long-term health impacts from flood events are potentially more severe than in other neighbouring areas; due to higher levels of social vulnerability.

Step i consists of the analyse of the variables used in the SFVI to define if they are appropriate for the context of a particular case study. Based on expert judgement and/or local experience

[102] Output Areas is a census division which usually contains between 110 and 139 households.

[103] In this document guidance is given to tailor the English SFVI, however, if the user feels confident to tailor a different index, the German Index available in the Library can be used, if considered more appropriate.

the ultimate aim of this step is to choose a set of variables that represent the four characteristics of the SFVI (financial deprivation, health, age and family structure). In Table 5.1 the variables within the financial and deprivation characteristic demonstrate the lack of capacity for financial recovery of a certain population after a flood event. In this case, for example, the user might find that "non-car ownership" does not demonstrate financial deprivation, but monthly salary does. The "long term sick" variable was chosen as it was seen that post-flood morbidity (and mortality) is significantly higher when the flood victims suffer from pre-existing health problems. Again, this variable might not be representative of the local context, and in that case would need to be replaced by one which is more suitable. Further explanations on the reasons why the variables were chosen can be found in Table 1 - Appendix B.

Hence, new variables can be added, and/or existing variables can be deleted. Once all the variables are chosen for each characteristic (it can be one or more for each characteristic), the data for each variable needs to be collected (Step ii).

If the user thinks the characteristics used in the SFVI are not relevant to their case studies, or they think new characteristics need to be considered, then it is suggested to go to Method B - Option 2.

Table 5.1: Characteristics, variables and data to apply the SFVI[104]

Characteristics	Variables	Data to be used
Financial / Deprivation	a) Unemployment	Unemployed residents aged 16 or more
	b) Overcrowding of households	Households with more than one person per room as a percentage of all households
	c) Non-car ownership	Households with no car as a percentage of all households.
	d) Non-home ownership	Households not owning their own home as a percentage of all households
Health	e) The long-term sick	Residents suffering from limiting long-term illness as a percentage of all resident
Household structure	f) Single parents	Lone parents as a proportion of all residents
Age	g) The elderly	Residents aged 75 and over as a percentage of all residents

Step ii: Data collection

The second step involves identifying whether the variables chosen in Step I are available from census data or other data sources. Therefore, the user should first look at the relevant national statistical web services that are available (e.g. for Spain, the Spanish National Institute of Statistics (INE) or for Italy the Italian National Institute of Statistics (Istat)). In other cases data

[104] Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. Phil. Trans. R. Soc. Lond. 360. 1511-1525.

collected by the regional offices or even municipalities may be used. For instance, in the Spanish case, data for certain variables has been collected from the Statistical Institute of Catalunia – at the regional level - or even from statistics collected by a local bank. These data were public, but this might not be the case in other countries.

Apart from Spain, the SFVI approach was also applied to the Portuguese case study, but in this case data availability was limited. First of all, data could not be found to the smaller level of disaggregation (the *freguesia*), but only for the next higher level (the *municipio*). Secondly, some of the variables could not be found at all, like for example “car ownership” and “overcrowding”, hence the financial deprivation characteristic was calculated using only two variables (unemployment and non-home ownership). In cases like this, if a variable is not found, it is suggested to return to Step i (i.e. choose other variables which can demonstrate financial deprivation or the characteristic which could not be represented due to a lack of data). In the case of Portugal, more work needs to be done involving local experts, with the aim of analysing the variables used to assess; 1) if they are appropriate (i.e. they represent the characteristic), 2) if those variables not included are essential, and if they are, other sources of data need to be identified, 3) if other characteristics need to be considered (in this case, METHOD B - Option 2 needs to be followed).

Step iii: Data treatment

Once the data is collected, the data could be transformed into percentages of the total population of the unit chosen (e.g. Municipality, district, etc.) for simplicity in the assessment. Table 2 shows the example for North Norfolk, England.

The data for each variable will then need to be analysed in terms of whether or not it is normally distributed, and it is recommended that users employ a standard statistical package (such as Excel, SPSS or R) to undertake this analysis. If the data is not normally distributed the most suitable transformation method should be applied (e.g. log natural or root square). If the data is normally distributed (as shown in Figure 5.3 for the case of the unemployment variable), there is no need to apply a transformation method. After all the data are normalised, Z scores should be applied to standardize the data. Users are directed to the many examples of online help and statistical textbooks which can provide guidance about statistical analysis including how to normalise the data or apply Z scores[105]. Information about how to perform these transformations and apply z scores in Excel is also provided in the Library.

Importantly, when choosing variables, care needs to be taken that variables are not correlated with one another (i.e. two or more variables demonstrating the same thing). In order to test this, statistical methods such as Factor Analysis are available, or it can also be determined by expert guidance. If two variables are highly correlated, then only one needs to be added.

[105] For example to calculate Z scores in SPSS: http://statistics-help-for-students.com/How_do_I_analyze_data_in_SPSS_for_Z_scores.htm#.VOhmJXysVWg (accessed 25.03.2015)

Table 5.2: Example of variables used for the SFVI applied in England

Output Area	Total population (%)	Age75+ (%)	Lone parent (%)	No car (%)	+1 persons /room (%)	Unem-ployment (%)	Rented property (%)
E00135385	100	6.7	3.9	9.2	0.6	2.6	22.5
E00135386	100	7.8	3.2	11.1	0.0	4.4	5.9
E00135389	100	0.0	0.6	0.7	0.7	6.5	94.5
E00135390	100	0.9	2.1	2.0	0.0	5.1	88.1
E00135391	100	7.4	2.6	7.1	0.0	5.2	27.7
E00135392	100	5.2	2.0	6.8	0.0	5.5	10.5
E00135393	100	11.9	3.3	8.0	0.0	4.1	19.7

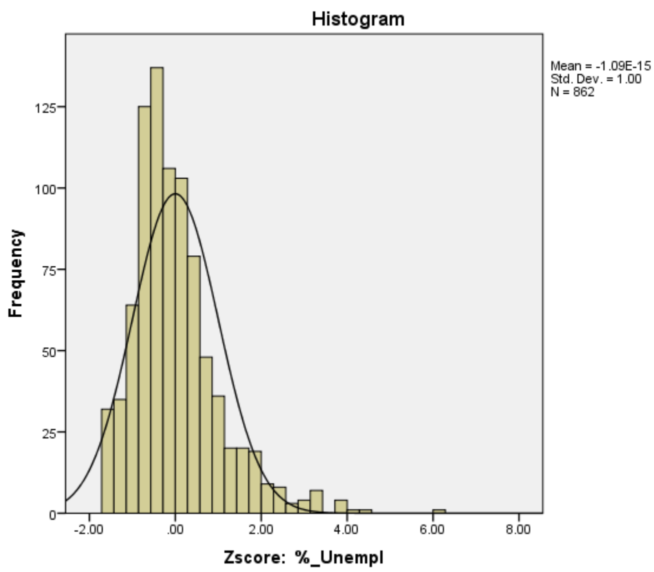


Figure 5.3: Histogram showing normal distribution for the case of unemployment in North Norfolk (UK) in 2011

Step iv: Calculation

A general equation can be used, and needs to be applied to each unit of analysis (e.g. each municipality):

$$\boldsymbol{SVI_{B1}} = \sum_{i=0}^{n}(\boldsymbol{W_i} * \boldsymbol{C_i})$$

Where

W= Weight of each category

n = Number of characteristics

C= Characteristics (average of the variables). See the example of the SFVI below.

The SFVI for England uses this general equation that can be used as an example for this step:

SVI_{B1}= e + f + g + ((a+b+c+d)*0.25)

Where:

SVI_{B1}= Social Vulnerability Indicator (Method B -Option 1)

e= Long-term sick

f= Single parents

g= The elderly

a= Unemployment

b= Overcrowding of households

c= Non-car ownership

d= Non-home ownership

The four variables (a, b, c, d) are averaged in the calculation for the financial deprivation.

Step v: Categorization and mapping

Each unit of analysis chosen (e.g. municipality, census sections, etc.) should have one value which represents the result of the calculation of the indicator (i.e. a value of social vulnerability) (See Table 5.3). Then, the results from all the units should be scaled in order to show results of the calculation. For example, for the Portuguese case:

[-1.6 , -1.2[→ Very low vulnerability

[-1.2 , -0.8[→ Low vulnerability

[-0.8 , -0.1[→ Medium vulnerability

[-0.1 , 2.5[→ High vulnerability

[2.5 , 5.7[→ Very high vulnerability

Categorization can be done using different methodologies. The three examples (Spain, Portugal and England) were categorised by identifying "natural breaks"[106]. Information on classification methods can be found at http://wiki.gis.com/wiki/index.php/Main_Page

Output maps and tables as shown in Figure 5.2 and can be produced using any GIS software.

[106] "Natural Breaks classes are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values. Natural breaks are data-specific classifications and not useful for comparing multiple maps built from different underlying information" (ESRI 2011, ArcGIS help).

Table 5.3: Example of output for the Barcelona region

Comuna	Sección	Distrito	Municipio	SFVI
08006	001	01	006	1.0
08006	002	01	006	0.1
08006	003	01	006	-0.6
08006	001	02	006	0.3
08006	002	02	006	3.3
08006	003	02	006	-0.5
08006	004	02	006	0.1
08029	001	01	029	-3.5
08029	002	01	029	-4.9
08032	001	01	032	-0.3
08035	001	01	035	-0.7
08035	002	01	035	0.2

In summary the key steps for these options are as follows:

i) Analysis of characteristics and variables;

ii) Collection of the data;

iii) Data treatment: If needed, transform the data according to the transformation method shown in Table 2 Appendix B. Standardize the variables as Z scores;

iv) Calculate using the equation $\boldsymbol{SVI_{B1}} = \sum_{i=0}^{n}(\boldsymbol{W_i} * \boldsymbol{C_i})$;

v) Categorize the resultant social vulnerability into five bands and, if possible map the results.

This option (Method B, Option 1) was already applied to North Norfolk (UK), Ria Formosa (Portugal) and Maresme region in Barcelona (Spain). In the case of the UK and Spain, the indicator was applied using the characteristics and variables suggested by Tapsell et al. (2002)[107], and in Portugal some data could not be found such as car-ownership. However, an analysis of the applicability of these variables for each case study still remains. For viewing the data collected and an example of the results see the "Population" category for Spain, Portugal and the UK in the Library.

[107] Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. Phil. Trans. R. Soc. Lond. 360. 1511-1525.

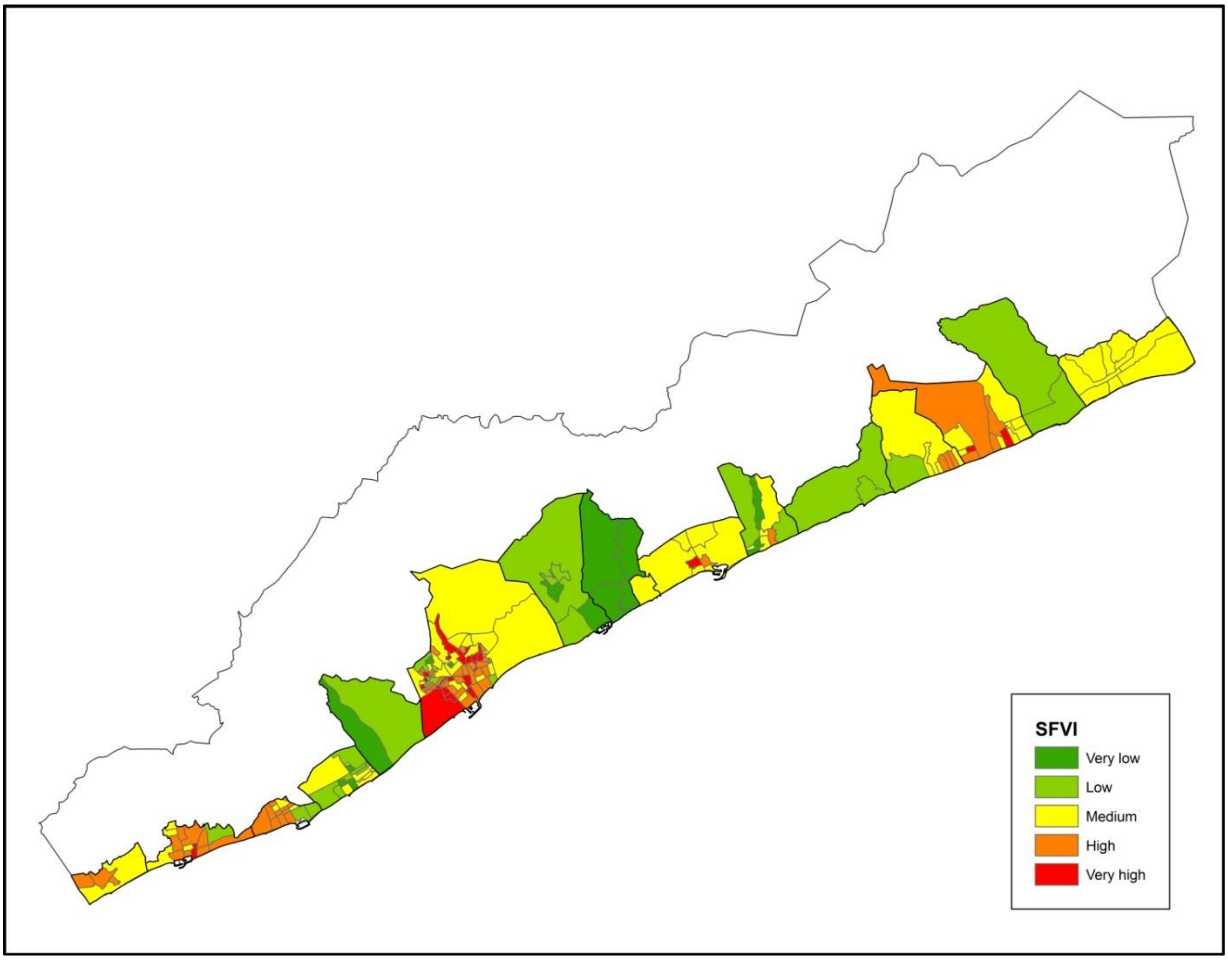


Figure 5.4: SFVI by Census sections. Maresme region (Barcelona, Spain)[108] [109] [110] [111]

Method B - Option 2: Developing a Social Vulnerability Indicator

Appropriate data to utilise an existing indicator may not be available or of sufficient resolution for the case study of interest. Alternatively, the characteristics applied for the Tapsell et al. (2002) SFVI[112] might not be considered to be appropriate within the context of the area of study. Additionally, certain characteristics which users or their stakeholders consider critical for measuring social vulnerability in the country or region of study were not included within the original SFVI. For example, for certain countries the presence of communities who do not speak

[108] INE (2011) Spanish National Census. http://www.ine.es/censos2011/tablas/Inicio.do (accessed 15.11.2014)

[109] INE (2001) Spanish National Census. http://www.ine.es/censo/en/seleccion_ambito.jsp?_IDIOMA=en (accessed 15.11.2014)

[110] La Caixa (2013) Anuario Económico de España. http://www.anuarioeco.lacaixa.comunicacions.com/java/X?cgi=caixa.anuari99.util.ChangeLanguage&lang=esp (accessed 15.11.2014)

[111] IDESCAT (2011) Base de dades de municipis i comarques. http://www.idescat.cat/territ/BasicTerr?TC=9 (accessed 15.11.2014)

[112] Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. Phil. Trans. R. Soc. Lond. 360. 1511-1525.

the local or native language can be an important issue for preparation, response and recovery stages of a natural disaster, especially in the European Union where the mobility of the population is high[113]. Hence in this case a new characteristic should be added (i.e. language). To overcome these deficiencies, users are therefore directed to create a new indicator; rather than maintaining the characteristics used in the SFVI. This means that some characteristics can be removed, and others added. In order to create an indicator, the following steps need to be followed, which are very similar to Method B - Option 1, except for the critical step of selecting the characteristics and variables *(Step i)*.

Step i: Selection of characteristics and variables

The aim of this particular step is to assess which characteristics are regionally and culturally relevant for the case study and which variable(s) are the most representative for each characteristic. The difference with Method B - Option 1 is that here the user might either add or eliminate characteristics from those considered in Option 1, in order to create a new indicator. For example, the user might consider it relevant to add the characteristic of ethnicity/language, or education (it might be the case in certain places where the level of education is a restraint to understand, for example the information for recovery after the flood). In the same way, users might consider other characteristics not relevant, such as health or family structure.

A fundamental step here is for the users to work with stakeholders and those who know about social vulnerability in their area to decide which characteristics should be included, and which variables better represent these characteristics. Previous coastal events may provide valuable indications of those who suffered most from flooding events and therefore may be used as a basis for the selection and justification of additional characteristics or variables.

A list of characteristics and variables associated with social vulnerability to the effects of floods is provided (Table 5.4) based upon a literature review. The user can consider these and determine the most appropriate characteristics and variable(s) based upon the social, economic and cultural context in the specific area of study and the problem which needs to be addressed. From a practical perspective, the selection of variables will also necessitate consideration of the data availability for the region of study (Step ii). Each variable in Table 5.4 has a sign: Negative (-) implies less vulnerable and positive (+) implies more vulnerable. This is important when including them within an 'additive' equation.

As part of the methodology, it is important to clarify and justify the selection of characteristics and related variables. An explanation of why each was chosen should be given, with local examples. For example: "The age of the population (i.e. percentage of those under the age of 5 years) is an important variable in this area, as families with young children were mostly affected in previous floods". "Language is a characteristic that needs to be considered: The population who do not speak the official country's language were found to be an important variable for the

[113] During the workshop we conducted for the plenary meeting (Bologna, November 2014), some concerns arose in relation to the areas where tourism is one of the main economic activities. Users were concerned that the variables used for the SFVI are not sufficient to show vulnerability of the temporary population. The purpose of the methodology to measure social vulnerability is to assess the vulnerability of the permanent population, and how resilient they are to recover from an impact. A temporary population or tourists will be affected during the storm, but the long-term effects of these population will not be assessed in the area of interest, as after the event they leave. The direct impact on temporal population is considered in the Risk to Life indicator.

region as there is evidence that it is difficult to make people more aware of floods or for warning systems".

Table 5.4: List of indicators most commonly found in the literature, and usually available from national Census data[114] [115] [116] [117] [118] [119] [120]

Characteristics	Variables	Impact[121]	Relation to flood event
Financial deprivation	Unemployed residents aged 16 or more	(+)	Lower socio-economic status is consistently associated with greater post-disaster distress and problems with recovery, especially for those who are uninsured.
	Overcrowding Households with more than one person per room	(+)	
	Low income families or income deprived	(+)	
	Non-car ownership	(+)	
	Households not owning their own home. Social renters.	(+)	Renters might not feel attached to the place, their home, or furniture. This might go against preparedness or response.
Health	Residents suffering from limiting long-term illness.	(+)	Morbidity and mortality is higher after a flood when affected people suffer from pre-existing health problems.
	Access to healthcare providers (hospitals,	(-)	Access to health care providers are important for the post-event

[114] Morrow, B. H. (1999) Identifying and mapping community vulnerability. Disasters 23(1). 11-18.

[115] Cutter, S.L., Boruff, B.J. and Shirley, W.L. (2003) Social vulnerability to environmental hazards. Soc Sci Q, 84 (1). 242–261.

[116] Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. Phil. Trans. R. Soc. Lond. 360. 1511-1525.

[117] Fekete, A. (2010) Assessment of Social Vulnerability for River-Floods in Germany. Doctoral thesis, University of Bonn, Germany.

[118] Wilson, T. (2008) Defining and Mapping Societal Vulnerability and Resilience: A literature review. Deliverable 3.7a. Flood Risk Management Consortium (FRMRC) Phase 2.

[119] Tapsell, S. and Priest, S. (2009) Developing a conceptual model of flood impacts upon human health. FLOODsite project report T10-09-02. http://www.floodsite.net/html/pub guidance.htm (accessed 25.03.2015)

[120] Cutter, S.L., Mitchell, J.T. and Scott, M.S. (2000) Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina. Annals of the Association of American Geographers, 90 (4). 713-737.

[121] Negative (-) implies less vulnerable and positive (+) implies more vulnerable

Characteristics	Variables	Impact[121]	Relation to flood event
	nursing homes, physicians).		stages. The lack of these will lengthen immediate relief and/or long term recovery.
Family structure	Lone parents.	(+)	Lone parents tend to have less income and have to cope with both children and the impact of a flood
	Families with large number of dependents.	(+)	They have limited finances to outsource care for dependents, and must juggle work responsibilities and care for the family.
Age	Residents aged 75 and over.	(+)	The elderly have less mobility, making evacuation difficult, or there is an increase in the incidence of medical conditions which makes people more vulnerable in all disaster stages (preparation, response and recovery). Most of the vulnerability indices use age as a social characteristic of vulnerability.
	Residents aged less than 5 years old.	(+)	Young children: are dependent on an adult for evacuating, for example. Recovery for children can be difficult due to the disruption of their normal routines and attachment to their lost possessions and home environment.
House types	Properties without first level. Properties with basement or sub-basement.	(+) (+)	Single story: people do not have a opportunity to bring furniture upstairs; those with basements are more exposed to floods.
Occupation	Professional or managerial. Clerical or labourer / Service sector.	(-) (+)	Some occupants, especially those who are involved in resource abstraction, can be severely affected. Also those working on services like housekeeping or childcare are affected as the demand also declines.

Characteristics	Variables	Impact[121]	Relation to flood event
Rural / Urban	High population density. Rural population.	(-)	Rural residents can be more affected as they are more dependent on locally based resource abstraction. High-density urban areas are also more vulnerable as evacuation gets more complicated.
Ethnicity/ Language	Non-official language speakers.		In areas where there are large migrant communities, language barriers may affect people during preparation and response stages and cultural factors may influence risk perception.
Insurance	Low uptake of insurance.	(+)	Insured households recover more quickly than those without any sort of insurance.
Transience	Low transience (or high length of residence).	(-)	Length of residence is a way of measuring prior experience on floods.
Education	High level of qualification attained. Low level of qualification attained.	(-) (+)	Linked to economic status, and lower education constrains the ability to understand warning information and access to recovery information.
Gender	Women	(+)	Women can suffer disproportionally during the recovery stage, for example due to lower wages, family care and more responsibilities in the home.

Step ii: Data collection

The key starting point for this is to use Census data at the lowest level of disaggregation available. However, it might be the case that data is not available either at a sufficient level of disaggregation or not existing for the latest Census. There are ways to overcome these difficulties:

- You can use other sources of data (e.g. regional statistics and private companies which have open access to their datasets);
- Some data for certain variables can be taken from a previous Census (in most of the countries, this should be 2000 or 2001). This is possible, as long as the limitations are considered and reported;
- Some data might not be available for certain levels of disaggregation and in this case higher levels might be used; this is also possible but similar to the point above as long as potential limitations are considered.

Importantly, when choosing variables, care needs to be taken to avoid double counting (using two or more variables which are indicating the same thing). Statistical methods such as factor analysis to test this can be used, or it can also be determined using expert guidance.

Important considerations for Step ii:

- Is the data available? How reliable is it? Is it up to date?
- To what level of disaggregation can the data be obtained? (Municipality, districts, or lower, like census sections In Spain or Output Areas in England). Does it allow users to identify differences within the region of study?

Step iii: Data treatment

Follow instructions as in Step iii for Method B - Option 1.

Step iv: Calculation

For each characteristic, calculate the average value depending on the number of variables. Then the following equation can be applied:

$$\mathbf{SVI_{B2}} = \sum_{i=0}^{n}(W_i * C_i)$$

Where:

SVI_{B2}= Social Vulnerability Indicator (Method B - Option 1)

n= number of characteristics

C = value of characteristic

W= weighted value for the characteristic

Step v: Mapping

For Step v follow instructions as in Step v, Option 1

In summary:

i) Select the appropriate characteristics and variables.

ii) Collect the data.

iii) Treat the data: If needed, transform the data according to the transformation method shown in Table 2 Appendix B. in Excel. Standardize the variables as Z scores.

iv) Calculate using the equation $\mathbf{SVI_{B2}} = \sum_{i=0}^{n}(W_i * C_i)$.

v) Categorize in five bands (Very Low, Low vulnerability, Medium, High, Very high), and map.

<u>Weighting</u>

Additionally, weights can be added accordingly ideally based on experts' opinions or stakeholders' experiences. Weighting represents the importance of the characteristic in relation to other characteristics, and it has to be adjusted in relation to the region or the country conditions. If weights are employed, a justification of their use should be given when building the indicator.

It is important to highlight here that independent of the Method used (A or B) the indicator should be tested or validated. Validation is recommended after a model (an index or indicator in this case) is built, in order to assess whether the indicator is working well and the results are showing a close to reality picture of vulnerability in the case study. The results produced by a new indicator could be examined a) intuitively by the person(s) who created the indicator or b) asking various informed stakeholders how well they feel that the new indicator reflects vulnerability as they understand it to be in the area of question. It is highly recommended that users go through the validation process once results have been obtained.

5.2 Risk to Life

5.2.1 Introduction to risk to life

Risk to Life is an indicator of the potential for injury or fatality during an event for a specific location. Although the number of deaths caused by flooding in Europe is relatively low compared with certain other hazards (particularly heat waves and earthquakes), the worst cases of death are usually related to coastal flooding, flood defence failure and flash floods[122].

There are numerous factors and characteristics (including, but not limited to: social, physical, political, cultural and environmental) which lead to a loss of life during flood events. In a comprehensive review of numerous studies, Jonkman et al.[123] provide a useful summary of the most significant characteristics and sensitivities in the context of risk to life. The events with the largest loss of life occurred:

- Unexpectedly and without substantial warning;
- At night;
- Where the possibilities for shelter were missing.

The authors continue by providing the most important determinants of the number of fatalities:

- The collapse of buildings in which people are sheltering;
- The depth of water;
- High flow velocities, which can lead to the collapse of buildings and from which people are unable to escape;
- The rapid rise of waters, this is especially hazardous, as people may be trapped inside buildings;
- The chances for survival are likely to be related to an individual's physical strength and stamina and his or her ability to find shelter.

In addition to the factors highlighted by Jonkman et al[124], Brazdova and Riha[125] also consider the presence of Disaster Risk Reduction measures such as evacuation and rescue activities, hydrological forecasting, the flood warning time and the response to it, as well as the flood characteristic, such as flood onset speed and the rate of water level rise, to be of high importance. Risk-taking behaviour, especially by males, has been another factor leading to fatalities during flood events[126]. The danger is not limited to the event itself; as individuals return to their homes and businesses to begin the recovery and clean-up process, the potential

[122] Green, C., Viavattene, C. and Thompson, P. (2011). Guidance for assessing flood losses. Deliverable 6.1 – FP7 EU Project CONHAZ 244159.

[123] Jonkman, S.N., Vrijling, J.K. and Vrouwenvelder, A.C.W.M. (2008) Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method. Nat Hazards (46). 353–389.

[124] Ibid.

[125] Brazdova, M. and Riha, J. (2013) A simple model for the estimation of the number of fatalities due to floods in Central Europe. Natural Hazards and Earth System Sciences Discussions, 1 (3). 2633-2665.

[126] Jonkman, S.N. and Kelman, I. (2005) An analysis of the causes and circumstances of flood disaster deaths. Disasters, 29. 75–97.

for injuries or death can continue due to unstable buildings and the presence of other dangers such as electrical cables[127].

Brazdova and Riha (2013) [128] analysed 35 questionnaires completed by professionals from the academic sphere, research institutes, engineering consultancies, river board agencies, administrative bodies, evacuation and rescue services and fire brigades and other populations affected by floods. More than 20 contributing factors to risk to life were identified; the most stated being preparedness of municipality, warning, rescue activities, water depth, flood extent, water velocity.

It is important to consider the kind of impacts that a body of water (moving at different velocities) will have on a person. Salaj (2009) [129] studied the effect of factors like water depth and velocity, and also the weight and height of persons, their gender, skills and type of clothing. The most important factors were water depth and velocity. The findings of this study broadly concur with that of Karvonen et al. (2000)[130]. Jonkman et al. (2002) concluded that people lose stability in flows in relatively low depth–velocity products. They obtained critical depth–velocity products for standing range from 0.6 m^2/s to about 2 m^2/s[131].

Many methods have been developed[132] [133] [134] [135] to assess potential risk to life from flood events, but most of them are limited to just a few characteristics as the cause of fatalities. A method which considers other aspects and distinguishes from all of these is the Flood Risks to People Project in the UK, as it was the only project which developed a different model to predict loss of life. This method is different in that fatalities for a particular event are calculated as a function of injuries, which in turn are estimated according to the flood, area, and population characteristics, rather than applying a uniform mortality fraction to the exposed population as in the other

[127] Ahern, M., Sari Kovets, R., Wilkinson, P., Few, R. and Matthies, F. (2005) Global Health Impacts of floods: epidemiologic evidence. Epidemiologic Reviews, 2005, 27. 36–46.

[128] Brazdova, M. and Riha, J. (2013) A simple model for the estimation of the number of fatalities due to floods in Central Europe. Natural Hazards and Earth System Sciences Discussions, 1 (3). 2633-2665.

[129] Cited in Brazdova, M. and Riha, J. (2013) A simple model for the estimation of the number of fatalities due to floods in Central Europe. Natural Hazards and Earth System Sciences Discussions, 1 (3). 2633-2665.

[130] Karvonen, T., Hepojoki, A., Huhta, H.-K. and Louhio, A. (2000) The use of physical models in dam-break analysis. RESCDAM Final Report, Helsinki University, 11 December 2000.

[131] Jonkman, S.N., Vrijling, J.K. and Vrouwenvelder, A.C.W.M. (2008) Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method. Nat Hazards 46. 353–389.

[132] Priest, S., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Wilson, T. (2008) Task 10: Building models to estimate loss of life for flood events. Executive Summary, FLOODsite Project, Report T10-08-10, HR Wallingford, UK.

[133] Jonkman, S.N., Van Gelder, P.H.A.J.M., and Vrijlink, J.K. (2002) Loss of life models for sea and river floods. In Wu et al. (eds.) Flood Defence 2002, Science Press, New York Ltd. Available: http://www.waterbouw.tudelft.nl/public/gelder/paper120b-v10210.pdf (accessed 16.08.07)

[134] Brown, C. and Graham, W. (1988) Assessing the threat to life from dam failure. Water Resources Bulletin, 24 (6). 1303 – 1309.

[135] Graham, W.J. (1999) A procedure for estimating loss of life caused by dam failure. Dam Safety Office report DSO-99-6.

studies [136]. The Risk to life model proposed by Priest et al. (2007)[137] is based on this method and includes new data collected from flood events in Continental Europe.

5.2.2 Methodology for assessing the potential risk to life during flood events

The Risk to Life indicator is considered Method A within the Library. It is a generic indicator, developed at EU level and using various sources of information. However, if the case study partners are aware of a different indicator which is ready available, already calculated and can be applied to their case studies, this can be added as Method A in the Library.

The Risk to Life model developed by Priest et al. (2007)[138] for the FLOODsite project[139] is considered the most appropriate option to measure the potential risk to life in the context of RISC-KIT for many reasons: it is easy to use, being accessible to both experts of different disciplines and non-experts; the input data should be easily available within all countries, and finally the fact that the method was developed with new data collected from floods events with fatalities in various European countries, makes it applicable to all the European sites. The methodology takes into consideration many of the important aspects identified by Jonkman et al. (2002)[140] in their comprehensive review of previous risk to life models, such as warning, evacuation and building collapse. Also the FLOODsite research, itself, undertook a comprehensive and exhaustive review of risk to life models as well as a statistical analysis of data on fatalities caused by past flood events. Table 5.5 shows the Risk to Life method developed for EU FP6 FLOODsite project.

[136] Cited in Priest, S., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Wilson, T.. (2008) Task 10: Building models to estimate loss of life for flood events. Executive Summary, FLOODsite Project, Report T10-08-10, HR Wallingford, UK.

[137] Priest, S., Wilson, T., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Fernandez-Bilbao, A. (2007) Building a Model to Estimate Risk to Life for European Flood Events – Final Report. FLOODsite project report T10-07-10, HR Wallingford, UK.

[138] Ibid.

[139] See http://www.floodsite.net/ (accessed 25.03.2015)

[140] Jonkman, S.N., Van Gelder, P.H.A.J.M., and Vrijlink, J.K. (2002) Loss of life models for sea and river floods. In Wu et al. (eds.) Flood Defence 2002, Science Press, New York Ltd. Available: http://www.waterbouw.tudelft.nl/public/gelder/paper120b-v10210.pdf (accessed 16.08.07)

Table 5.5:FLOODsite Risk to Life method[141]

<table>
<tr><th>DEPTH x VELOCITY
MID-RANGE</th><th>NATURE OF THE AREA</th><th>OUTDOOR HAZARD</th><th>RISK TO LIFE FROM FLOODING</th><th>MAIN FACTOR LEADING TO FATALITIES</th></tr>
<tr><td rowspan="3">>7m^{2}s^{-1}</td><td>3. High vulnerability
(including mobile homes,
campsites, bungalows and poorly constructed properties)</td><td rowspan="6">Extreme danger for all</td><td rowspan="3">Risk to life in this scenario is extreme as not only are those in the open very vulnerable to the effects of the flood waters but those who have also sought shelter are also very vulnerable due to the fact that building collapse is a real possibility</td><td rowspan="4">Hazard and building collapse dominated (A)</td></tr>
<tr><td>2. Medium vulnerability
(Typical residential area mixed types of properties)</td></tr>
<tr><td>1. Low vulnerability
(Multi-storey apartments and masonry concrete and brick properties)</td></tr>
<tr><td rowspan="3">1.10 to
7 m^{2}s^{-1}</td><td>3. High vulnerability
(including mobile homes, campsites, bungalows and poorly constructed properties)</td><td>All those exposed to the hazard outside will be in direct danger from the floodwaters. Those living in mobile homes will be at risk from the high depths and velocities and those in single storey dwellings will be at risk from not being able to escape to upper floors. Those in very poorly constructed properties will also be vulnerable from structural damages and/or building collapse.</td></tr>
<tr><td>2. Medium vulnerability
(Typical residential area mixed types of properties)</td><td>All those exposed to the hazard outside will be in direct danger from the floodwaters. Damages to structures are possible. Those in unanchored wooden frames houses are particularly vulnerable. With very deep waters there is the risk of some not being able to escape.</td><td rowspan="3">Hazard Dominated (B)</td></tr>
<tr><td>1. Low vulnerability
(Multi-storey apartments and masonry concrete and brick properties)</td><td>All those exposed to the hazard outside will be in direct danger from the floodwaters. In this scenario those residing in these properties have the lowest risk although structural damages are still possible in wooden properties</td></tr>
<tr><td rowspan="2"></td><td>3. High vulnerability
(including mobile homes,
campsites, bungalows and poorly constructed properties)</td><td rowspan="2">High dangerous for most</td><td>Those outside are vulnerable from the direct effects of the floodwaters. In addition, those in single storey dwellings will be vulnerable in deeper waters. People will also be afforded little protection in mobile homes and campsites. Those in very poorly constructed properties will also be vulnerable from structural damages and/or building collapse. Vehicles are also likely to stall and lose stability.</td></tr>
<tr><td>2. Medium vulnerability
(Typical residential area mixed types of properties)</td><td>Anyone outside in the floodwaters will be in direct danger. It is at this point where behaviour becomes significant as structural damages are less likely; those inside should mostly be protected. Vehicles are likely to stall and lose stability. Are people undertaking inappropriate actions such as going outside when is it not necessary?</td><td>Behaviour dominated (C)</td></tr>
</table>

141 Priest, S., Wilson, T., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Fernandez-Bilbao, A. (2007) Building a Model to Estimate Risk to Life for European Flood Events – Final Report. FLOODsite project report T10-07-10, HR Wallingford, UK.

0.50 to 1.10 m^2s^{-1}	**1. Low vulnerability** (Multi-storey apartments and masonry concrete and brick properties)		Anyone outside in the floodwaters will be in direct danger from the floodwaters. It is here at this point where behaviour becomes significant as structural damages are less likely so those inside should be on the most part protected. Vehicles are likely to stall and lose stability. Are people undertaking inappropriate actions such as going outside when is it not necessary?	
0.25 to 0.50 m^2s^{-1}	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Moderate dangerous for some	Only the most vulnerable should be in direct danger from the floodwaters. (e.g. children and the elderly); in this category the shelter may not protect them. Motor vehicles may become unstable at these depths and velocities. Those in very poorly constructed properties may also be vulnerable from structural damages.	People vulnerability dominated though some behaviour-related fatalities (D)
	2. Medium vulnerability (Typical residential area mixed types of properties)		Only the most vulnerable should be in direct danger from the floodwaters (e.g. children and the elderly). Motor vehicles may become unstable at these depths and velocities. Those who seek shelter should be safe.	
	1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)		Only the most vulnerable should be in direct danger from the floodwaters. (e.g. children and the elderly). Motor vehicles may become unstable at these depths and velocities. Those who seek shelter should be safe.	
<0.25 m^2s^{-1}	**3. High vulnerability** (including mobile homes, campsites, bungalows and poorly constructed properties)	Low caution	A very low risk to adults either out in the open or who is in a property. There may be a threat to the stability of some vehicles even with these low depth-velocity factors.	Low risk (E)
	2. Medium vulnerability (Typical residential area mixed types of properties)			
	1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties)			

The method comprises two input components:

Flood hazard factors: The depth-velocity product is calculated by multiplying the flood depth by the flood velocity.

Area vulnerability factors: Three categories are proposed to indicate different vulnerabilities for locations affected by flooding. This factor takes into account the likely people affected by an event as well as the potential for shelter. The categories are based on four main factors: Type of land use, number of floors of a property, structural integrity of buildings (e.g. including the types of building material and the structural integrity of construction) and the presence of particularly vulnerable groups.

In order to calculate the potential risk to life for a specified area (e.g. neighbourhood, specific site or buildings), the following steps, based in Priest et al. (2007)[142], are proposed:

Step i

Define the site to be assessed. This can be of any size (a neighbourhood, a school ground, a camping site, etc.).

Step ii

Define the nature of the area (i.e. Low, Medium or High) in terms of land use, type and quality of construction of building (see column "Nature of the area in Table 5.5). This can be deduced from expert knowledge of the area, site visits, local land development plans or satellite image interpretation. Method B can be applied if there is a type of property present in the area of study which is not included in the present indicator. Then the method can be tailored adding new types of construction to the nature of the area[143].

Step iii

Define the hazard. Calculate the depth-velocity product for the event according to the hazard characteristics resulting from the hazard model. If there are areas with different values of depth/velocity, the area should be divided in relation to this. Waves are not considered in this indicator, so the user might want to add a seafront buffer strip, which could be classified as an area with a depth-velocity product >$7m^2s^{-1}$.

Step iv

Use Table 5.6 to define a preliminary result for Risk to Life looking at the colour classification (Green = Low, Yellow = Medium, Orange = High and Red = Extreme Risk). However, this is a qualitative method, and each of the cells has its own description, which can be seen in Table 5.5. Another factor that needs to be included at this point is the vulnerability of people. However, this will only need to be considered if a result falls in a cell containing the letter D (See Table 5.6). For the cells containing an A or B, everyone is considered to be vulnerable irrespective of their characteristics. For the case of "Risk to Life," a person vulnerability is mostly deduced from the age (i.e. elderly and very young population as less able to cope if in floodwaters). Data on percentages of these groups in relation to the total population should be available for all the countries from national statistics websites.

Step v

Results can be illustrated using a map, by overlaying a hazard map of the depth/velocity product with a vulnerability map, which can contain information on the nature of the area, the population component (vulnerability).

[142] For more detailed information on this methodology, see http://www.floodsite.net/html/project_overview.htm (accessed 25.03.2015)

[143] This is of particular importance for Bangladesh.

Table 5.6: Simplified table in the Library[144]

		Nature of the area		
		1	2	3
Depth/Velocity	<0.25 m^2s^{-1}	E	E	E
	0.25 to 0.50 m^2s^{-1}	D	D	D
	0.50 to 1.10 m^2s^{-1}	C	C	B
	1.10 to 7 m^2s^{-1}	B	B	A
	>7m^2s^{-1}	A	A	A
1. Low vulnerability (Multi-storey apartments and masonry concrete and brick properties) **2.** Medium vulnerability (Typical residential area with mixed types of properties) **3.** High vulnerability (including mobile homes, campsites, bungalows and poorly constructed properties)				

[144] Priest, S., Wilson, T., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Fernandez-Bilbao, A. (2007) Building a Model to Estimate Risk to Life for European Flood Events – Final Report. FLOODsite project report T10-07-10, HR Wallingford, UK.

6 Vulnerability Indicators for ecosystems

6.1 Introduction to ecosystem vulnerability indicator

Coastal habitats are already heavily degraded in European regions predominantly as a result of erosion and human development[145]. Extreme storm events may increase such pressure and accelerate the deterioration of some of these ecosystems. Coastal ecosystems are adapted to face coastal storms and therefore their conservation can be promoted by an ecosystem-based approach. Indeed coastal wetland ecosystems provide a range of ecosystem services, including coastal protection through wave energy dissipation[146]. Intertidal marshes also play important roles in fine sediment sequestration and stabilization, including carbon burial[147], they sustain the productivity of estuarine and open coast ecosystems[148] and have high conservation and resource value[149]. These ecosystems also provide other services: they are valuable recreational sites and important habitats for specialized plants and animals including migratory and breeding waterfowl and other birds[150].

However, these systems, even if adapted, may need time to recover from extreme events and this recovery will depend on their status, on the existence of alternative habitats, on other existing pressures and on the role of human management in their recovery[151]. During this recovery phase they may not fully provide these services and, therefore, a vulnerability assessment should carefully consider the potential changes in the delivery of these ecosystem services.

These coastal ecosystems are not the only ones exposed on the coastal strip to extreme events, other ecosystems such as agriculture, forests and groundwater are not as adapted to coastal flooding and also have to be considered as impacted particularly by saline intrusion. For instance, the increase in salinity and frequency of flooding reduce the ability of trees to generate[152]. A study on the impacts of Hurricane Katrina reported the inland saltwater intrusion

---

[145] European Environment Agency (2010). 10 messages for 2010 – coastal ecosystems. At: http://www.eea.europa.eu/publications/10-messages-for-2010-coastal-ecosystems (accessed 25.03.2015)

[146] Gedan, K. B., Kirwan, M. L., Wolanski, E., Barbier, E. B. and Silliman, B. R. (2010) The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. Climate Change 106. 7–29.

[147] Chmura, G.L., Anisfield, S.C., Cahoon, D.R. and Lynch, J.C. (2003) Global carbon sequestration in tidal, wetland soils. Global Biogeochemical Cycles 17. P1111.

[148] Mitsch, W.J., Gosselink, J.G. (2007). Wetlands (4th edition). Wiley, Hoboken, N.J.

[149] Costanza, R., d'Argfe, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeeem, S., Oneill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature 387. 253-260.

[150] Reise, K., Baptist, M., Burbridge, P., Dankers, N., Fischer, L., Flemming, B., Oost, A.P. and Smit, C. (2010). The Wadden Sea—a universally outstanding tidal wetland. Wadden Sea Ecosystem 29 (Common Wadden Sea Secretariat, Wilhelmshaven). 7-24.

[151] European Environment Agency (2006). The changing face of Europe's coastal areas. Report No 6, European Environment Agency.

[152] Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S. and Woodroffe, C.D. (2007) Coastal systems and low-lying areas. Climate Change 2007: Impacts, Adaptation

in groundwater following the Hurricane Katrina has impacted on trees and plants, such as rice fields, taking up to two years to recover[153]. Salt water flooding usually causes more damage to crops and soils as high salt concentrations cause crop stress, restricted growth and death[154].

6.2 Methodology for assessing ecosystems vulnerability

A number of studies have used a vulnerability index approach to evaluate general coastal zone vulnerability, almost exclusively focusing on the single forcing factor of sea level rise. The Coastal Vulnerability Index (CVI) concept was first used by Gornitz (1990)[155] to evaluate the potential risk of the U.S. East Coast to the impacts of sea level rise. Subsequently, Thieler and Hammer-Klose (1999) [156] followed this approach integrating six physical variables ranked according to their potential contribution to shoreline change. The variables were analysed to produce a vulnerability index expressing the relative sensitivity of coastal areas to sea level rise. These two indicators, however, assess mostly the physical characteristics of the coast, not including the ecosystems in particular.

One of the first studies assessing ecosystems was by McFadden et al. (2007)[157], within the INTEREGG IIIB BRANCH project, who attempted to develop a CHVI (Coastal Habitat Vulnerability Index (CHVI)) for NW Europe based around four physical variables being seen as particularly important controls on the vulnerability of saltmarshes and mudflats: (1) rate of relative sea-level rise, weighted by tidal range, (2) process environment, (3) accommodation space, including the effects of defences and (4) sediment supply.

Within the EU FP7 THESEUS project[158] an Environmental Vulnerability Index (EVI) was developed indicating the potential changes in a habitat following a storm event for different types of ecosystems. Depending on the level of change, the ecosystem might recover to the original state; however certain changes are so drastic that natural recovery of the receptor is very unlikely without human intervention. The EVI results show on a scale from 0 to 3 the different levels of changes (See Table 6.1). Even though the indicators used in THESEUS consist of different methods, the advantage of the EVI is the consistency in the outputs, meaning that for

and Vulnerability, contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK. 315-356.

[153] Williams, V.J. (2010). Identifying the economics effects of salt water intrusion after Hurricane Katrina. Journal of sustainable development 3 (1).

[154] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

[155] Gornitz, V.M. (1990) Vulnerability of the East Coast. Journal of Coastal Research, Special Issue 9. 201–237.

[156] Thieler, E.R. and Hammer-Klose, E.S. (1999) National Assessment of Coastal Vulnerability to Future Sea Level Rise: Preliminary Results for the U.S. Atlantic Coast. U.S. Geological Survey Open-File Report. 99-593.

[157] McFadden, L., Spencer, T. and Nicholls, R.J. (2007) Broad-scale modelling of coastal wetlands: what is required? Hydrobiologia 577. 5-15.

[158] Zanuttigh, B., Sitta, G. and Simcic, D. (2014). THESEUS Decision Support System User Manual. FP7 Theseus project 244104.

most of the indicators there is the same scale (0 to 3), facilitating comparisons between ecosystems. The other advantage is that these indicators have the possibility to be used for extreme events, not only sea level rise due to climate change, as for most of the others previously reviewed. The THESEUS approach was therefore considered the most appropriate for use in the context of this project.

Table 6.1: Scale used for the Environmental Vulnerability Indicator (THESEUS Project)[159]

Scale	Description	Explanation
0	**Negligible**	Negligible impact to habitats/species
1	**Transient effect no long term change anticipated**	Changes within the range of a receptor's natural seasonal variation and full recovery is likely within a season.
2	**Moderate effect/Semi permanent change**	Changes are beyond a receptor's natural seasonal variation. Partial recovery is possible within several seasons, but full recovery is likely to require human intervention, or greater than 20 years for natural recovery.
3	**Permanent effect/change**	Changes are so drastic that natural recovery of receptor is very unlikely without human intervention. Or natural recovery will take longer than 20 years.

The Ecosystems Vulnerability Indicator (EVI) estimates the lack of resilience by indicating the period of recovery for certain hazard thresholds. A potential change to an ecosystem may induce a temporary or permanent loss of ecosystem services[160]. Due to the fact that for most natural ecosystems it is difficult to evaluate the loss of services associated to them; the assessment of ecosystems in the library is limited to the recovery time, but will be further explored in Task 2.3. The case of crops (also included within this category) is different. Crops are easier to assess as the indicators can demonstrate the loss of value associated with the loss of the ecosystem (i.e. by knowing the crop yield reduction and its market value). The indicators for crops in the Library do not indicate change as those for the natural ecosystems, but potential yield loss. The Library comprises three indicators for crops:

- Two indicators for salt tolerance: one for "*relative salt tolerance*" for most of the types of crops which are present in the case study countries. This indicator is based on three different studies[161] [162] [163] which explored the relative crop loss due to the presence of

[159] Zanuttigh, B., Sitta, G. and Simcic D. (2014) THESEUS Decision Support System User Manual. FP7 Theseus project 244104.

[160] TEEB (2010) The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Editor: Kumar P.. Earthscan, London and Washington.

[161] European Union. Directorate - General for Agriculture and Rural Development (2012) Agriculture in the European Union. Statistical and Economic information report 2012, European Commission.

[162] Maas, E.V. (1984) Crop tolerance. California Agriculture.

salt in the soil. The output is a threshold of soil salinity up to which there is no yield loss. The other one is an indicator of *potential yield decrease from soil salinity*, and it measures this decrease for certain crops considering different threshold values of salt content in the soil[164]. It is recommended to use this indicator in the first instance; however, as not all types of crops are included, the user might need to use the relative salt tolerance indicator instead. These indicators internationally applicable as they were not developed for any particular area;

- An indicator of "*yield loss due to flooding*" measures the yield loss for different flood durations. The loss also depends on the growing season and can be expressed in monetary term or as a percentage of unflooded yield[165]. This indicator is readily available for France, Bangladesh and the UK. To be applied in other agricultural regions, the indicator will have to be tailored according to differences in the growing seasons. This is explained under Method B.

These indicators were also categorized on a scale of four levels of vulnerability, ensuring a consistent methodology with that applied for the other indicators.

6.2.1 Method A: Using existing indicators

Table 6.2 lists the types of ecosystems included in the Library, with a short explanation of the purpose of the indicator, the hazard thresholds, and the source of information. The Ecosystem Vulnerability Indicators are listed by default for all the countries in the Library (except for the case of crops that has specific indicators for France, the UK and Bangladesh). The user will need to use only the types of ecosystems which are present in their area of interest. It is important to mention that those indicators developed by the Cambridge Coastal Research Unit are based on the THESEUS methodology.

The confidence in some of these indicators however, may remain limited, due to the fact that either they were not validated or they were developed for specific sites and not generalised. In such case, they might not be representative of the vulnerability of other sites. Therefore, Table 6.2 also indicates whether an indicator is generic (i.e. built to be applied in different contexts), or site specific. Despite the inherent limitations, the indicators presented here are the best possible for the scale and purpose of the Indicator Library. These generic indicators can be applied directly to the case studies using Method A (i.e. crops, mangroves, seagrasses, freshwater marshes, saltmarshes, rocky shores and biogenic reefs, and the two indicators for salt tolerance); the specific indicators might need some tailoring using Method B.

---

[163] Tanji, K.K. and Neeltje, C.K. (2002) Agricultural Drainage Water Management in Arid and Semi-Arid Areas. FAO Irrigation and Drainage Paper 61, Food and Agriculture Organization of the United Nations, Rome.

[164] Cardon, G., Davis, J., Bauder, T. and Waskom, R. (2014) Managing saline soils. Colorado State University. At: http://www.ext.colostate.edu/pubs/crops/00503.html (accessed 18.3.2015)

[165] Penning-Rowsell, E.C., Priest, S., Parker, D.J., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and coastal erosion risk management. A manual for economic appraisal Routledge, London.

Table 6.2: Ecosystem Vulnerability Indicators included in the Library

Type of ecosystem	Indicator purpose	Sources	Hazard Factors	Generic indicator?
Sand dunes	To provide an estimate of the extent of change in environmental conditions of each ecosystem	Theseus Project	▪ Inundation frequency ▪ Flood duration	No. Plymouth. UK.
Grasslands		Theseus Project	▪ Inundation frequency ▪ Inundation duration	No. Plymouth. UK.
Woodlands		Theseus Project	▪ Inundation frequency ▪ Inundation duration	No. Plymouth. UK.
Rocky shores		Theseus Project	▪ Sedimentation ▪ Duration o sedimentation ▪ Proportional increase in storm intensity from current conditions	Yes.
Biogenic reefs	To provide an estimate of the extent of change in the environmental conditions (including Sabellaria reefs, Mussel beds and Oyster beds)	Theseus Project	▪ Sedimentation depth (cm) ▪ Duration of the sedimentation (hours) ▪ Proportional increase in storm intensity from current conditions	Yes
Saltmarshes	To provide an estimate of the extent of change in environmental conditions from major storms	Cambridge Coastal Research Unit	▪ Geomorphic setting ▪ Tidal range ▪ Presence /absence of mudflats ▪ Presence / absence of a barrier ▪ Return period of different surge water levels ▪ Wave characteristics	Yes
Freshwater marshes	To provide an estimate of the extent of change in environmental conditions from major storms, including flooding with sea water.	Cambridge Coastal Research Unit	▪ Frequency of flooding with sea water ▪ Inundation duration	Yes
Seagrasses	To provide an estimate of the extent of change in environmental conditions from major storms and cyclones.	Cambridge Coastal Research Unit	▪ Species of seagrass present or leaf length ▪ Sediment burial depth	Yes
Mangroves	To provide an estimate of the extent of change in environmental	Cambridge Coastal Research Unit	▪ Maximum sustained wind speed ▪ Likely frequency of	Yes

	conditions from major storms and cyclones.		major storms with these wind speeds	
Crops	Indicator of potential yield decrease from saline soils measures the relative yield decrease of a certain crop in accordance to the content of salt in the soil	Cardon et al (2014)[166]	▪ Concentration of salt in soils	Yes
	The indicator of salt tolerance is a comparative indicator between crops. It tells how vulnerable is one crop in relation to the other, taking into account the maximum soil salinity without yield loss	Mass (1984) [167] Tanji and Neeltje (2002)[168]	▪ Concentration of salt in soils	Yes
		Yield loss due to flooding: Penning Rowsell et al[169]	▪ Flood duration ▪ Season of the year	No (developed for England)
		Yield loss (France) Ministère de l'écologie, du développement durable et de l'énergie[170]	▪ Water depth ▪ Velocity of current ▪ Flood duration ▪ Season of the year	No. (developed for France)

6.2.2 Method B: Developing or tailoring Ecosystem Vulnerability Indicators

It is suggested that those indicators which are not generic in Table 6.2 should be adapted to the specific case study of interest, and in this case there are also two Options.

[166] Cardon, G., Davis, J., Bauder, T. and Waskom, R. (2014) Managing saline soils. Colorado State University. At: http://www.ext.colostate.edu/pubs/crops/00503.html (accessed 18.3.2015)

[167] Maas, E.V. (1984) Crop tolerance. California Agriculture.

[168] Tanji, K.K. and Neeltje, C.K. (2002) Agricultural Drainage Water Management in Arid and Semi-Arid Areas. FAO Irrigation and Drainage Paper 61, Food and Agriculture Organization of the United Nations, Rome.

[169] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2014) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal. London.

[170] Ministère de l'Ecologie, du Développement Durable et de l'Energie (2014) Analyse multicritères des projets de prévention des inondations. http://www.developpement-durable.gouv.fr/Publication-du-guide-et-du-cahier.html (accessed 20.11.2014)

Method B – Option 1: Tailoring existing Ecosystem Vulnerability Indicators

The aim of this option is to tailor the existing indicator for the particular case study with the help of local stakeholders and/or local experts. A way of doing this is by looking at the scale of the indicator for each hazard threshold (i.e. 0 to 3). The table should be changed in accordance with the answers from participants by lowering or increasing the numbers, always within the same scale (0-3). For instance, for sand dunes in Figure 6.1, it could be asked to local stakeholders if they agree with the fact that sand dunes can be permanently affected after a flood-duration of two days with a storm frequency of every 20 years. If the answer is yes, then there is no need to change the scale (remains 3). Or, if they observed changes in the sand dunes during a storm of 6 hours, then the scale should be changed to 1, for example.

The indicator of loss due to flood duration (within Crops) will have to be adapted by all the countries (except for France, the UK and Bangladesh) by tailoring the table which appears under Method B in the Library (See Table 6.3). This is due to the fact that this table was created for the UK, hence the crop growing season is different from other countries. The scale of the indicator depends on the yield season, being the highest impacts during the growing stage. This is what should be examined in the table and changed as appropriate. For example, in England the highest loss of crops for most of the species will be June, July and August, being the period of full development of plants.

Return to Ecosystems

Ecosystems - Sand Dunes

Method A

Method A consists on using existing indicators as they are developed. This means the user can use the methods recommended in the library or any other they consider more appropriate for their case studies.

Duration (Days)							1	2	3	4	5	6	7	14	28	
Duration(Hours)[1]	0.5	1	2	4	6	12	24	48	72	96	120	144	168	336	672	Permanent
Frequency every 100y	0	0	0	0	0	1	2	3	3	3	3	3	3	3	Sub-tidal[2]	Sub-tidal[2]
Frequency every 20y	0	0	0	0	0	1	2	3	3	3	3	3	3	3	Sub-tidal[2]	Sub-tidal[2]

Indicator scale:

Negligible
0 Negligible impact to habitats / species

Transient effect (no long term change anticipated)
1 Changes within the range of Receptor's natural seasonal variation and full recovery is likely within a season

Moderate effect/Semi permanent change
2 Changes are beyond Receptor's natural seasonal variation. Partial recovery is possible within several seasons, but full recovery is likely to require human intervention, or greater than 20 years for natural recovery

Permanent effect/change
3 Changes are so drastic that natural recovery of receptor is very unlikely without human intervention. Or natural recovery will take longer than 20 years

[1] If we are thinking about storm events and storm surges, then the duration range should be from 2 hours to 5 days
[2] Sub-tidal is the new habitat created

i Click here for more information on EVI for Sand Dunes

Figure 6.1: Example for "Sand Dunes"

Table 6.3: Indicator for yield loss[171]

	Yield loss as % of unflooded yield						
	Crops[1]					Grass [2]	
	Winter cereals	Spring cereals	Roots	Oilseed rape	Spring peas	Grazed	Cut
Month	% loss	% loss	% loss	% loss	% loss	% loss	% loss
October	Red	Green	Orange	Red	Green	Yellow	Yellow
November	Yellow	Green	Green	Yellow	Green	Yellow	Yellow
December	Yellow	Green	Green	Yellow	Green	Green	Green
January	Yellow	Green	Green	Yellow	Green	Green	Green
February	Yellow	Yellow	Yellow	Yellow	Green	Green	Green
March	Yellow	Orange	Yellow	Yellow	Orange	Yellow	Yellow
April	Yellow	Yellow	Orange	Yellow	Orange	Yellow	Yellow
May	Orange	Orange	Red	Orange	Red	Yellow	Orange
June	Red	Red	Red	Red	Red	Yellow	Orange
July	Red	Red	Red	Red	Red	Yellow	Yellow
August	Red	Red	Red	Red	Orange	Yellow	Yellow
September	Green	Orange	Red	Orange	Green	Yellow	Yellow

Notes: Figures in parenthesis show yield losses for flood of less than 1 week where different
1 reduction in expected harvested yield in a year without floods
2 reduction in expected annual yields of grass dry matter and energy from grass

Red	Greater than 66% loss	Yellow	Between 1 and 33% loss
Orange	Between 33 and 66%	Green	No loss

Method B - Option 2: Redeveloping an indicator

If the user considers that an indicator listed in Table 6.2 is not appropriate for the case study, an alternative method should be considered. This is a more complex option as it involves revising the method in order to redevelop the indicator. This will need the participation of scientific experts in the area (e.g. ecologists, biologists, coastal geomorphologists, etc.), with specific knowledge on coastal ecosystems. They might know of the existence of other indicators which can be applied, and in this case, if they can be used without tailoring, they should be added to Method A.

[171] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J., Owen, D. (2014) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal, London.

7 Systemic Vulnerability Indicators

This section of the Library helps to identify systemic impacts. Here, systemic impacts are understood to mean how the direct loss caused by a hazard propagates within and between different systems generating other losses beyond the hazard area, as well as delaying the recovery. Which systems to be considered may vary from one case to another depending on what is at risk but also from different stakeholders' perspectives[172]. Thus from an emergency perspective, the considered system may be limited to the road network for access and the location of emergency services and shelters. The Chamber of Commerce will be interested in disruption to business and how this may affect the economy post disaster. A power grid manager will be concerned with the interruption of electricity supply to the population. Such analysis could be carried out for different groups of stakeholders.

A system refers in general to a set of elements interconnected and somehow organized, providing functions and outputs. Systems exist at different scales, are dependent on sub-systems and in turn contribute to larger systems. A multi-system, multi-scale approach may then be necessary to explore the overlap between the different systems and to reveal the complexity of altering one or another. System can be approached as a black box. An alternative approach could be to define the system by characterizing the different elements and interconnections related to the exposed area and, then, to define the system boundaries to a certain degree. To do so, a requirement is the identification of the links between node points, the capacity or flow attached to these links, and also the functional relationship between inputs and outputs at each node.

Nodes receive inputs, and as a result produce outputs (products, services). Nodes can be characterized by a number of functions of production, and it is important to understand how their function may be altered. Having a good understanding of the function of production is essential (for instance time to produce, capacity, and inflexibility).

Networks can be defined simply as providing support to flows. Some networks may support only one type of flow (e.g. gas, water), whereas others may convey different types of goods (road networks). The type of elements flowing within a network may alter the capacity. The flow is also time-dependant (daily peak, seasonality). A network may be or not a physical structure (road, electricity, water). Non-physical networks will partly depend on an existing physical network (a supply chain depends on roads and freight). The spatial distribution of a network and its nodes define the existing relationships, the uniqueness, the adaptability and the boundaries of the system and can have significant effects. This should be considered carefully when assessing systemic vulnerability[173].

The key is, therefore, to evaluate how those relationships may either mitigate or amplify the magnitude of the initial impact. If node B was an isolated point, then the vulnerability of B is simply the physical vulnerability of B to this particular form of impact. However there is a great

[172] Green, C., Viavattene, C. and Thompson, P. (2011) Guidance for assessing flood losses. Deliverable 6.1 – FP7 EU Project CONHAZ 244159.

[173] Costanza, B., Simicevic, A., Galderisi, A., Ceudech, A., Ferrara, F.F., Profice, A., Parker, D., Tapsell, S., Costa, L., Kropp, J., Foerster, E., Vagner, A., Melissourgos, Y. and Sapountzaki, K. (2010) Analysis of vulnerability factors versus space. Deliverable 3.2 EU Ensure Project 212045.

chance, that B is part of a chain of relationships looping back as illustrated in Figure 7.1. For example, an intrusion of salt into an ecosystem managed for fishery production will cause the reduction of the economic activity; which will eventually cause the fishery to close. This may produce unemployment, population decrease and ecosystem disruption.

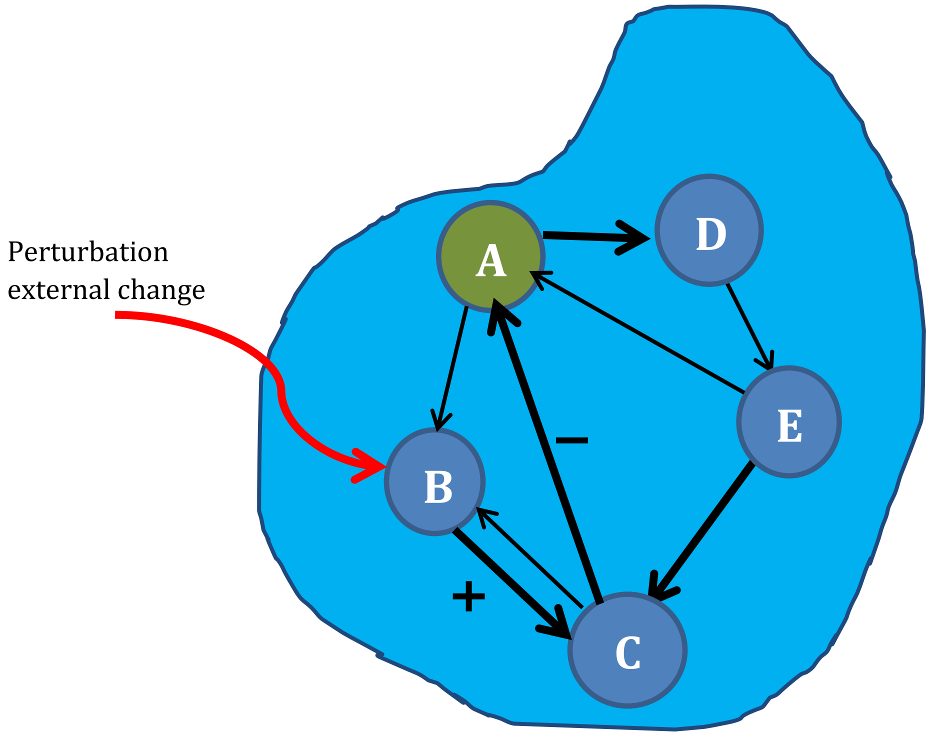


Figure 7.1: Systemic vulnerability[174]

It is difficult to provide a common conceptual model for assessing the systemic vulnerability. However the following key points have to be considered as a starting point:

- Dependencies and interdependencies of different elements of these systems with one another;
- The degrees of uniqueness of given functions which may be lost temporarily;
- The potential for surrogates to reflect or transfer lost functions in space and possibly also time;
- Prioritisation of some functions is vital for more than one system;
- It is not always about physical integrity;
- The boundaries may be not limited to the territorial space;
- Scale effect;
- Vulnerability may be pre-existing due to physical geographical, cultural, economic constraints;
- A non-optimal system under normal conditions may be less vulnerable than an optimal system following the stress of an event (e.g. redundancy may be good as an event is a vector of scarcity and chaos);

[174] After Green, C., Viavattene, C. and Thompson, P. (2011). Guidance for assessing flood losses. Deliverable 6.1 – FP7 EU Project CONHAZ 244159.

- The importance of other systems as a support of the recovery (resilience).

In the Library, approaches and examples are proposed to the user to identify which systems to consider, and how to characterize and map these systems in order to reveal their Systemic Vulnerability.

In RISC-KIT, the following systemic aspects have been considered:

- Critical Infrastructure: electricity, water, road and rail networks;
- Business Disruption: beach frontage urban area and tourist resort, port and related commercial and industrial zones, coastal harbour (with or without marina) and related urban area.

Although these are the systems identified as being of greatest importance to the project, this list is not exhaustive and users should consider additional systems or assets which may be important locally, for example telecommunications infrastructure or an airport. The templates and guidance provided here should assist with the assessment of any additional systems.

7.1 Critical Infrastructure

The Critical Infrastructure Template for assessing systemic impacts will guide the user through the process of identifying vulnerability within a specified system. This could apply, for example, to an electricity grid or a transport network. Examples are given for each system and these will enable the user to better understand the recommended process for assessing each system's vulnerability. In the appendix of this document, further information on each system is provided.

The template employs a five-step approach (Figure 7.2) which guides the user through the assessment process:

The 5 step approach

1	Approach stakeholders: ascertain the importance of the system; collect data
2	Produce a table listing the key components
3	Produce a schematic of the system
4	Map the schematic diagram
5	Develop a narrative to describe the vulnerability of the selected system and its potential consequences for the overall system

Figure 7.2: Snapshot of the template page illustrating the 5-step approach

Step 1 - Approach stakeholders: ascertain the importance of the system; collect data

	Contact	Organisation	Email	Telephone	Comments
1					

Some Key questions to ask the stakeholder:
1. Where are the assets located? Define the nodes and network links of the system.
2. How vulnerable is each asset to: a) floodwater b) overwash c) erosion?
3. Under which circumstances will the performance or the asset be compromised? When will the asset cease to function?
4. What defence or mitigation measures are in place? Are these measure well maintained/up-to-date?
5. How 'unique' is the asset: i.e. How will the system cope without it? Can it be bypassed?
6. What is the typical repair time to fully reinstate the asset? Does this require manpower (how many persons)?

Figure 7.3: Snapshot of the "Step 1 Stakeholders Table"

For certain systems, information on assets and networks may not be publicly available so it will be necessary to approach stakeholders in order to gain knowledge and access to data. A risk assessment may have already been carried out for the system, for counterterrorism or public health purposes for example, and although this may not be specific to coastal hazards, it is likely to be transferable – at least in part – for the purposes of the project. The table in Step 1 (Figure 7.3) can be used to record the details of the stakeholder(s) and some key questions are provided to assist with the gathering of crucial information. At the end of step one, the user will have an idea of whether further assessment for that particular system is necessary and, if so, will have the required data to be input into the table in Step 2.

Step 2 - Produce a table listing the key components

	Asset[1] ID (assign a unique code)	**Asset[1] Description**	**Input[2]**	**Output[3]**	**Capacity**	**Likelihood of Exposure ?** (High, Med, Low, None)	**Sensitivity** (High, Med, Low, None)	**Is the asset unique[4]?** (Yes/No)
2								

[1] An asset may be technological (electricity substation, water treatment plant etc.) or a business or ecosystem etc. [2] Detail the asset or assets which feed into this one and assign them each an asset ID. [3] Detail the assets d
will depend on whether the system can cope without the asset functioning. Can the asset be bypassed or replaced by another asset in the system? [5] Surrogate measures are alternative solutions to temporarily replace the

Figure 7.4: Snapshot of the "Step 2 Assets table"

The table in Step 2 (Figure 7.4) aims to characterise the individual assets within a given system, and by doing so will identify the nodes and the network flows (see above) within the system. It is worth highlighting that an asset may not only be technical or man-made. Natural features, such as a beach or nature reserve, should also be considered as an asset. The user may need to prioritise which aspects of the system to consider rather than simply producing an exhaustive list. For example, when conducting a regional assessment, only the road network between towns should be considered. The road network within a town can simply be represented as a junction.

A series of fields are listed in the table which will be used to capture information required for the proceeding steps. These are as follows:

- Asset ID – This is a unique code used to identify only that particular asset. If the asset is represented in another system, the code needs to be consistent throughout. A short combination of letters and numbers may be the most appropriate method, avoiding special characters such as punctuation marks. For instance, each electricity substation of the power network may be identified by the code SB associated with an ordinal number (SB1, SB2, SB3,);

- Asset Description – Details the type of asset (e.g. primary substation);
- Input – List the asset(s) (using a unique asset ID) which feed into this particular asset. For instance for a distribution substation, the asset id of a primary substation will be listed here;
- Output - List the asset(s) (using a unique asset ID) which are fed by this particular asset. For instance the asset ID of the residential areas deserved by the distribution substation will be listed here. In some circumstances this may be a two-way dependency which can be represented by having the same asset(s) listed in both the input and output fields. An example of this may be a two-way road;
- Capacity – A number and unit appropriate for the particular system. For example, this could be the number of vehicles per hour on a road, the voltage of a substation or the population of a town. Average values should be used;
- Likelihood of Exposure - (High, Med, Low, None) Indicating if the asset is likely to be directly exposed to the hazard;
- Sensitivity – (High, Med, Low, None) Indicating the potential level of damage. This will depend on the exposure (above) for if there is no exposure, the sensitivity can be ignored;
- Is the asset unique? - (Yes/No). Can the asset be bypassed or replaced by another similar asset in the system?;
- Surrogate measures – This highlights the potential for alternative, emergency solutions to temporarily replace the lost functioning of the services (e.g. bottled water instead of mains water or a mobile water treatment plant);
- Dependency – Which additional factors are essential to operate the asset, such as manpower, water and/or power supply;
- Estimated repair time – The duration (in hours or per days) needed to restore the asset to its pre-event capacity;
- Prioritisation –Some assets (including of the same type) may be regarded as more 'important' than others. This would usually be the case for a hospital, which may be given priority of repair in order to aid recovery time or additional redundancy measures to lessen any negative impacts. Scale these assets with a score of 1-5, where 1 is the highest level of priority given. This category may not be applicable to most types of asset.

Step 3 - Produce a schematic of the system

Map the assets detailed in Step 2 showing their relationship using a flow diagram (See Figure 7.5). Use the same shape for each type of asset and label with the unique asset ID assigned in Step 2. This will allow you to visualise the dependencies and interdependencies of the system.

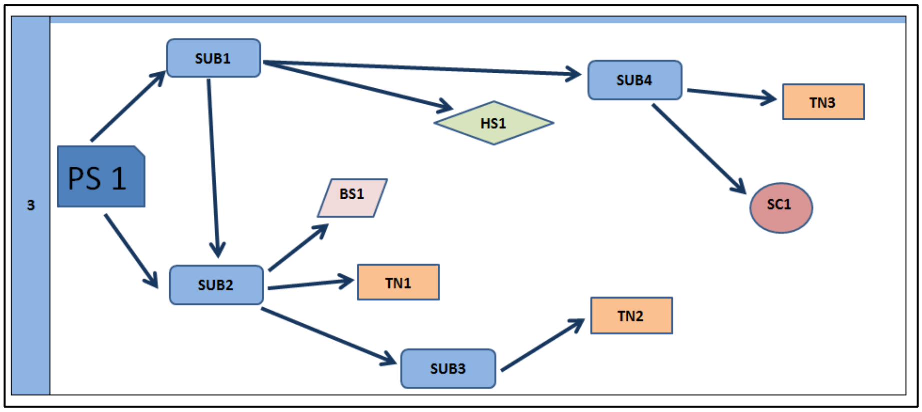


Figure 7.5: Example of a flow diagram for the electricity network

Step 4 - Map the schematic diagram[175]

Transfer the schematic into a geographically defined format (See Figure 7.6). The most appropriate method is to use GIS software.

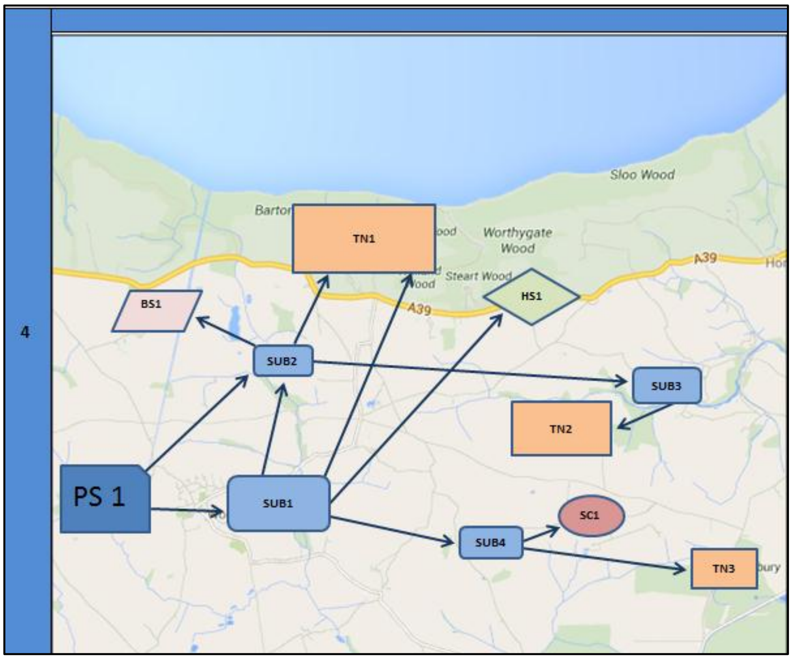


Figure 7.6: Example map of electricity assets based on the schematic for Step 3

Step 5 - Develop a narrative to describe the vulnerability of the selected system and its potential consequences for the overall system

In cooperation with stakeholders, and based on the output from the previous Steps, it essential to create a narrative explaining the range of possible impacts on the given system and on other,

[175] In some cases you may find easier to map the assets as the information is available in such format. In such case, use Step 4 first to list the assets and to produce your schematic.

interlinked, systems. This should take into consideration the number or importance of any assets impacted, the level of disruption caused locally/regionally and the possible knock-on impacts to the wider geographical area. This could take the form of a 'what-if' analysis and should ultimately result in an assessment of how vulnerable the systemic is (None, Low, Medium or High). This decision will require inputs from, and discussion with, a wide range of stakeholders.

7.2 Business Disruption

The Template for assessing Systemic Business vulnerabilities within the Library is generically similar to the Critical Infrastructure Template. However, it contains a number of important differences which are explained below. In appendix H of this document, further information is provided. This appendix is designed to help users identify the steps that should be considered when assessing the disruption potential of businesses and the coastal business setting which best describes their site. It should also help to work up a vulnerability assessment and narrative.

Proportionality

As with all assessments, it is important to make the assessment of business impacts proportionate. To aid this we describe two approaches. The first is a descriptive analysis (i.e. (a) below) and the second is a descriptive <u>and</u> quantitative analysis of the disruptive impacts of an event and disruptive vulnerability (i.e. (b) below).

(a) Vulnerability analysis (Descriptive) – this may be described as a lighter touch, descriptive approach. This approach recognises that primary data collection is resource-intensive and may not be justified for some assessments. Where this is the case, a lighter touch, descriptive approach may be more appropriate.

(b) Vulnerability analysis (Descriptive and Quantitative) – this is a more detailed and penetrating approach which seeks to estimate disruptive impacts of an event on businesses in terms of lost value added. It incorporates the descriptive approach and extends it further. How primary data collection could be undertaken to estimate impacts specific to the region under consideration is explained. This approach may be appropriate where a more in-depth analysis is justified.

Coastal infrastructure and business inter-dependencies in coastal settings

In coastal business settings there is very likely to be an inter-dependence between coastal infrastructure and businesses i.e. often the character of businesses in coastal settings is directly associated with the attractiveness and accessibility of beaches, promenades, piers, harbours, roads, port infrastructure and natural assets such as sand dunes or wetlands. If these are damaged or lost temporarily then the businesses which depend on these will be undermined. There are likely also to be some businesses which are less directly dependent, or perhaps completely non-directly dependent, upon the coastal infrastructure but these businesses will probably also be adversely affected by an extreme event which damages or disrupts businesses. If infrastructure assets are lost forever because of an extreme flood event, then a different form of vulnerability assessment will need to be undertaken which considers the closure and relocation of businesses. This is not discussed here, but it could be considered using similar methods and will form an important aspect of the descriptive analysis (in Step 6, below).

It is necessary therefore to consider and to examine:

a) How businesses are dependent upon coastal infrastructure, and;

b) How businesses are dependent upon one another.

Supply chains

Supply chains describe the inter-dependency of businesses. Figure 7.7 is an example of a hotel supply chain in which the hotel supplies services to a range of customers and the hotel is supplied with a range of goods and services from other businesses arranged in tiers (e.g. businesses in Tier 1 or supplied by business in Tier 2, and so on). In the case of a large 'hub' port, such supply chains will be complex and will almost certainly have global reach, but in the case of hotels, local or regional sourcing of goods and services is likely to be common.

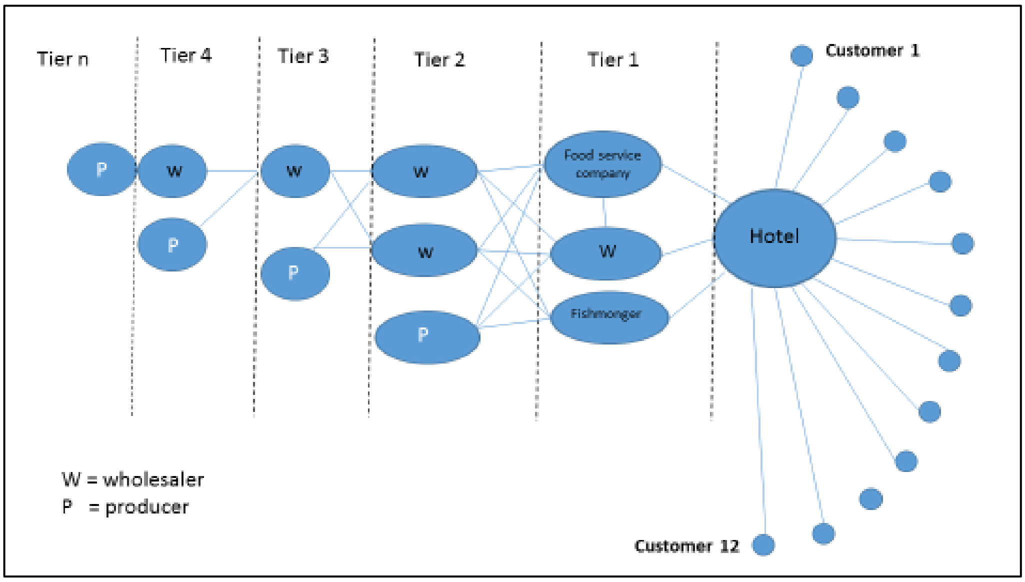


Figure 7.7: Example of a hotel supply chain[176]

Managing supply chains in order to reduce the risks of disruption means a loss of supply chain efficiency and performance – in other words it costs money which is a direct reflection of expected potential costs of disruption. On the other hand, ignoring disruption risks in order to optimise supply chain efficiency and performance runs the risk of costly supply chain interruptions. Whichever way – either by increasing supply chain disruption resilience or by ignoring it – costs money and is a potential way of measuring the costs of systemic disruption.

There are two types of supply chain disruption risk. There are recurrent risks (most commonly these are demand fluctuations that managers must deal with in supply chains) which require companies to focus on efficiency in improving the way they match supply and demand. Secondly, there are unscheduled disruptive risks (e.g. extreme natural events including coastal flooding and accompanying storms) which require companies to build resilience despite additional cost. Extreme coastal floods are likely to be disruptive or very disruptive. Disruptive risks of this sort tend to have a domino effect on the supply chain. An impact in one area — for example, a flood or a fire in a supply plant — ripples into other areas. Such a risk cannot be addressed by holding additional parts as inventory without a substantial loss in cost efficiency.

[176] Akkaranggoon, S. (2010) Supply Chain Management Practices in the Hotel Industry: An Examination of Hotel Food Supply Chains in South West England. DPhil, Management Studies, University of Exeter, Exeter.

By contrast, recurrent risks such as demand fluctuations or supply delays tend to be independent. They can normally be covered by good supply chain management practices, such as having the right inventory in the right place. Reliance on sole-source suppliers, common parts and centralized inventories has left supply chains more vulnerable to disruptive risks[177][178].

The template for assessing business systemic vulnerability has a 6-step approach (Figure 7.8)

The 6 step approach

1	Select which coastal business setting best describes the site
2	Approach stakeholders to acquire key data
3	Produce a table listing the key assets
4	Map the schematic diagram
5	Map the key assets (and links where feasible)
6	Develop a narrative to describe the vulnerability of the selected system and its potential consequences for the overall system

Figure 7.8: Snapshot of the "Business Disruption Template page" illustrating the 6-step approach

Step 1 – Select which coastal business setting best describes the site

There are three generic coastal business settings which, between them, are likely to describe the vast majority of sites or locations where a vulnerability assessment is likely to be required:

- Beach frontage urban area and tourist resort;
- Port and related commercial and industrial zones;
- Coastal harbour (with or without marina) and related urban area.

Step 1 involves identifying which type(s) have to be assessed. In turn this will aid the identification of the types of business assets that are likely to be present and also the coastal infrastructure that they are likely to be dependent upon. Appendix H of this document provides details of both the common types of coastal infrastructure and business assets likely to be found in each of these coastal business settings.

Step 2 - Approach key stakeholders to acquire key data

Undertaking a business systemic vulnerability assessment usually involves contacting one or more stakeholders in order to obtain information and data about the inter-dependencies which exist between coastal infrastructure (e.g. beaches, piers etc.) and business assets, and the

177 Chopra, S. and Sodhi, M.S. (2004) Managing Risk to Avoid Supply-Chain Breakdown. MIT Sloan Management Review 46 (1). 53-61.

178 Tang, C.S (2006) Robust Strategies for Mitigating Supply Chain Disruptions, International Journal of Logistics Research and Applications 9. 33-45.

linkages between businesses. If a quantitative vulnerability assessment is to be added to the descriptive one, then further data will be required and this may well involve undertaking a survey of major businesses. Basic stakeholder contact information may be recorded in the table provided in Step 2 of the Template.

Step 3 - Produce a table listing the key assets – the Asset Matrix

The table in Step 3 (Figure 7.9) aims to characterise the coastal business system. Because coastal businesses are commonly dependent upon coastal infrastructure, the table, or Asset Matrix, lists both a) the principal components of the coastal infrastructure and b) the major business assets. Users will need to prioritise the components of both systems to be considered rather than producing an exhaustive list. Smaller businesses will need to be grouped and labelled as 'Other Businesses' and their number, average employment size etc. recorded in the Matrix.

							More detailed quantitative approach	More detailed qualitative approach						
3	Column:	1	2	3	4	5	6	7	8	9	10	11	12	
		Asset ID (assign a unique code)	Asset Description	Input	Output	Number of businesses, length (m), capacity(c), mean or visitor count per day (v)	Average number of employees per business	Size distribution of business (Micro 0-9; Small/Med 10-249, Large 250+)	Likelihood of Exposure? (high, medium, low, none) (i.e. direct exposure to flooding)	Sensitivity to damage/loss (high medium, low, none)	Is the asset unique to sub-region? (Yes/No)	Surrogate measures	Dependency (list factors)	Esti dur repair, ment the 52 disr
	(IS) Infrastructure assets													
	(BA) Business assets													

Notes
1 It is necessary to calculate this value for businesses in each of the three size categories. This is done as follows: Multiply the Average Number of Employees per business by the Average Earnings per
(a) (b) Sensitivity to damage/loss includes (a) direct physical damage and/or (b) indirect, consequential loss
N/A - Not applicable
BA - All Business Assets
IS - All Infrastructure Assets

Figure 7.9: A snapshot of the "Step 3 Asset Matrix"

At the outset it is necessary to identify the major businesses and groups of businesses within the coastal locality and the region in which it is located if the chosen boundaries for the assessment are regional. Initially, the focus should be mostly upon the local scale (including the businesses located in the extreme flood zone and those beyond it).

The Asset Matrix contains 17 fields of data, although only 11 of these require data if the vulnerability assessment is to be a descriptive one only, otherwise data are required for all 17 fields. The Asset Matrix contains two sections: 1) Infrastructure assets and 2) Business assets and both should be listed with the requisite data. The fields are as follows:

- <u>Asset ID</u> – This is a unique code used to identify a particular asset. If the asset is represented in another system, the code needs to be consistent throughout. A short combination of letters and numbers may be the most appropriate method, avoiding special characters such as punctuation marks. For example, a beach may be labelled as

B1 to distinguish it from a second beach, B2. A promenade and sea wall might be labelled PSW. Tourist and visitor accommodation in hotels, guest houses (e.g. Bed and Breakfast establishments) and self-catering units might grouped together and labelled ACC;

- Asset Description – A brief description of the asset. This is free text for information only e.g. Pier or Holiday Camp;
- Input - List the asset(s) (using their unique asset ID) which are feed into this particular asset. For example, seaside accommodation is often dependent upon the attracting customers through accessible beaches and so an input to accommodation will be one or more beaches. In reality, use of beaches may be to some extent dependent upon the existence of accommodation which makes it possible for visitors to stay close to the beach (i.e. there is a reciprocal relationship);
- Output – List the asset(s) (again using the unique asset ID) which are fed by this particular asset. For example, food and drinks suppliers will be dependent on orders from hotels so in this case the output will be the food and drinks suppliers. Again, in reality, there will be a reciprocal relationship between businesses;
- Number of businesses, length (m), capacity (c) or visitor count (v) – this is any or a combination of the number of businesses, the length of the asset (e.g. a beach) in metres; the estimated capacity of a infrastructure component (e.g. a pier) in terms of the maximum number of people allowed on it at any one time or the maximum number of bed spaces in the case of accommodation; or the mean number of visitors counted using an asset (e.g. a beach) over a defined period of time;
- Average number of employees per business – the mean number of employees (full-time equivalent) employed by a business or group of businesses. This data may be acquired from primary or secondary sources;
- Size distribution of businesses - the number of businesses in each of the following three employment size categories;
- Likelihood of exposure – (High, Medium, Low, None). This indicates whether the asset is likely to be directly exposed to the coastal event and the estimated degree of exposure;
- Sensitivity to damage/loss – (High, Medium, Low, None). This indicates the estimated potential level of direct flood damage (a) or indirect/consequential loss (b). This will depend on the exposure (above) for if there is no exposure, the sensitivity can be ignored;
- Is the asset unique to the region ? – (Yes/No) The level of uniqueness will depend on whether the system can cope without functioning. The question is whether the asset can be bypassed or replaced by an alternative in the region?
- Surrogate measures – This highlights the potential for alternative solutions to temporarily replace the lost functioning of an asset.
- Estimated duration of repair/reinstatement – (Weeks in the 52 week year disrupted). The total duration of time in weeks (n) (measured as n/52) before pre-event levels of production or turnover are achieved after the disruptive event.
- Average earnings per employee per annum (Euros) – the mean earnings per employee for each business or business group. The mean earnings are likely to vary according to business size (see above) and an earnings value is required for each business size category.
- Value of lost working hours per business during disruption – these values are derived as a result of the product of a) the average employee numbers and b) average earnings per employee per annum and c) the estimated duration of disruption.

- Recovery factor - the Recovery Factor is a value which describes the amount of business lost over the period of business disruption. In many cases, businesses will be able to undertake some business – albeit at a reduced level – during the post flood period of disruption and the Recovery factor is designed to take account of this.
- Estimated value of business disruption (Euros) - This is the gross value added lost as a result of disruption. It is derived from the product of the number of businesses of different size (Column 7 of the Asset Matrix); the value of lost working hours per business per disruption; and the Recovery Factor. The result is Gross Value Added lost because of disruption.

Step 4 – Produce a schematic diagram

Map the coastal infrastructure assets and the business assets as a schematic diagram which portrays the linkages and inter-dependencies between all of the major assets in the Asset Matrix (Figure 7.10). Distinguish between coastal infrastructure and business assets by either different shapes or colours and label each with its unique asset ID. This schematic diagram will enable you to visualise the major inter-dependencies in the coastal business system.

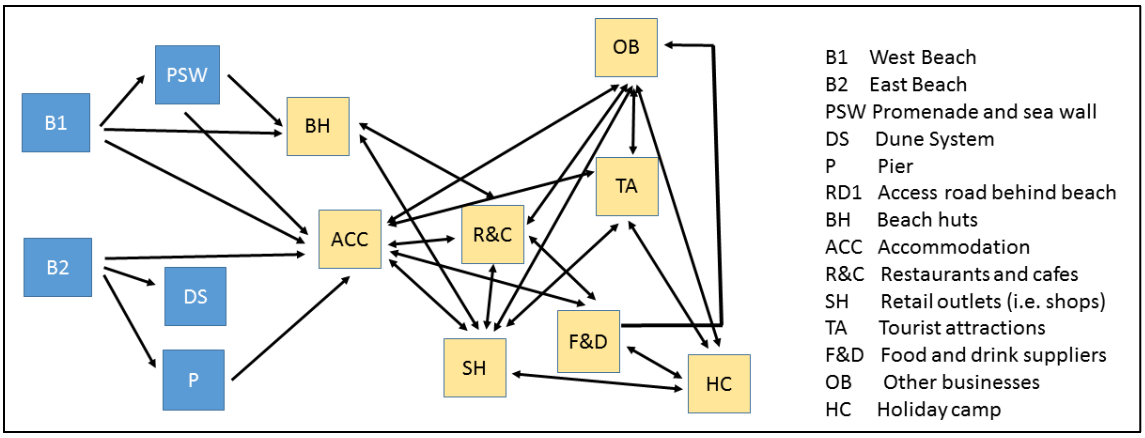


Figure 7.10:Example of an inter-dependency diagram for a coastal business setting distinguishing between coastal infrastructure assets and business assets

Step 5 - Map the key assets (and links where appropriate)

Transfer the schematic diagram into a geographically defined format (Figure 7.11). The most appropriate method may be to use GIS software. Figure 7.11 (and Figure 7.10 on which it is based) maps the major assets in the locality surrounding a coastal urban area. However, if the analysis and vulnerability assessment is to be undertaken at a regional scale, it will be necessary to also identify major business assets and inter-dependencies across the region as is portrayed in Figure 7.12. In this case, the Food and Drinks supplier in the coastal urban area is supplied by four businesses in its supply chain (i.e. S1 to S4 inclusive). In turn these businesses are supplied by three farms (F1 to F3 inclusive). The Asset Matrix would simply reflect the regional scale of analysis by adding these businesses into the matrix.

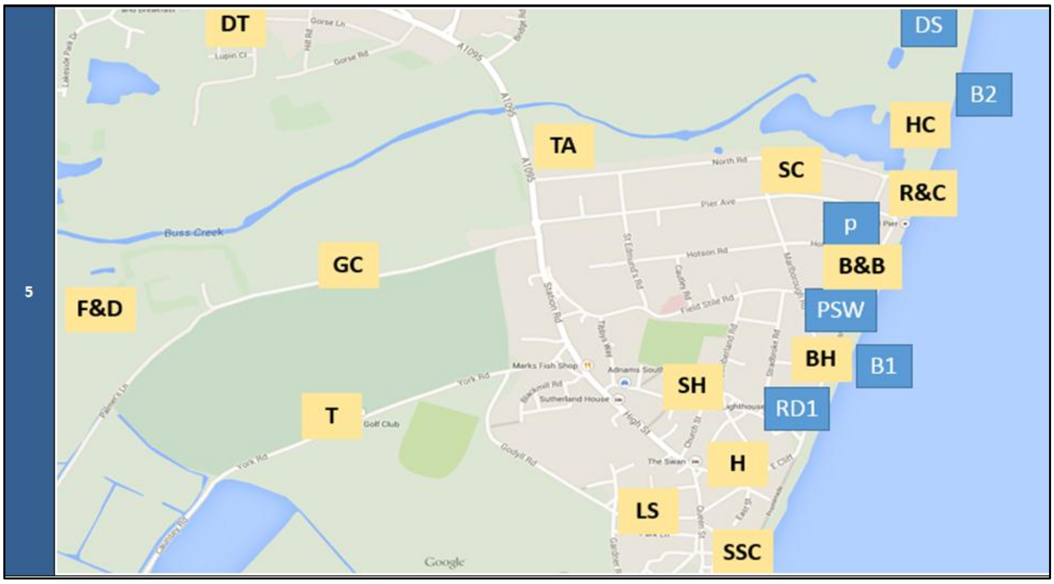


Figure 7.11: Example of a map of coastal infrastructure and business assets (without links in the case)

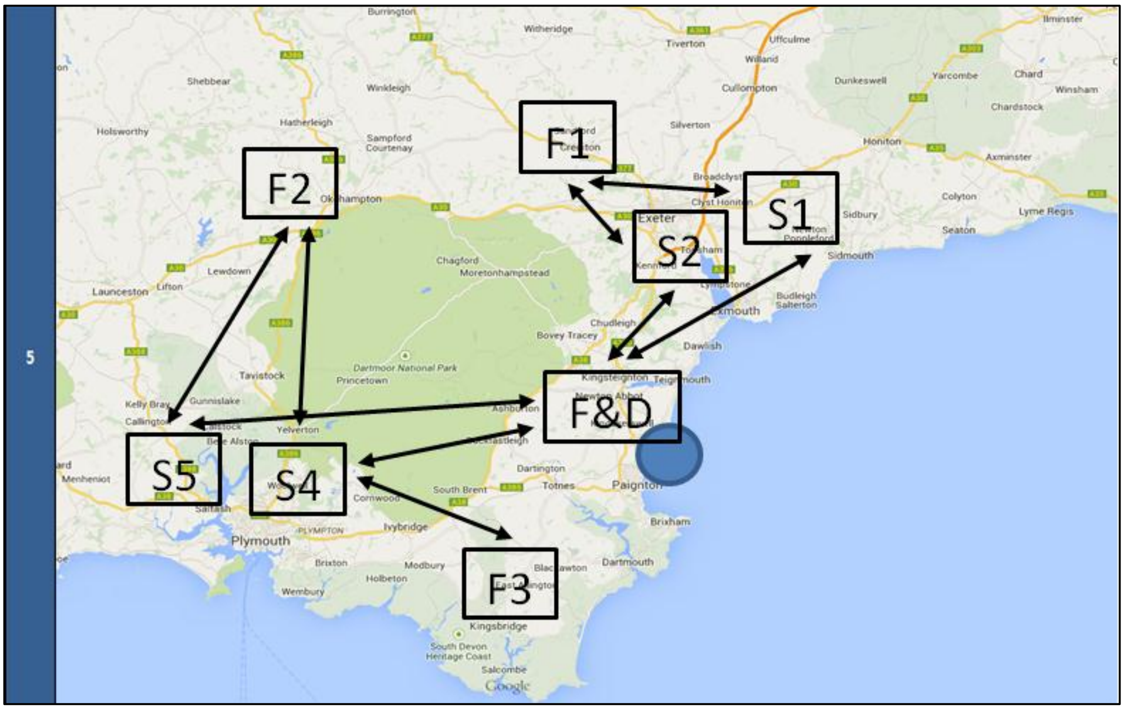


Figure 7.12: Example of map of business assets and inter-dependencies with the locality mapped in the previous step

Step 6 - Develop a narrative to describe the vulnerability of the selected system and its potential consequences for the overall system

In cooperation with stakeholders, and based on the output from the previous Steps, it essential to create a narrative explaining the range of possible impacts on the given system and on other, interlinked, systems. This should take into consideration the number or importance of any impacted assets, the level of disruption caused locally/regionally and the possible knock-on impacts to the wider geographical area. This could take the form of a what-if analysis and should ultimately result in an assessment of how vulnerable the systemic is (none, low, medium or high). This decision will require input from, and discussion with, a wide range of stakeholders.

8 Disasters Risk-Reduction Measures

The purpose of including Disaster-Risk Reduction (DRRs) measures in the RISC-KIT Library is to allow users to be able to include existing DRRs and account for their influence on different categories of vulnerability; as well as to assess the potential effects on vulnerability of introducing new DRRs. DRR measures can be accessed via a single button on the category page of the Library. This has been structured by the type of DRR measures, rather than within a single category or vulnerability indicator, as each DRR measure may influence multiple aspects of vulnerability. Table 8.1 illustrates the DRR measures that are included in the Library and highlights how they are mapped onto three of the categories of vulnerability (Built Environment, Population and Ecosystems) and the specific indicators are provided. Systemic vulnerability and disaster risk reduction is described in a separate section.

There are four ways in which the mitigative effects of DRRs have been included within the assessment of vulnerability (specific details of the most appropriate approach(es) and instructions for application are provided in the Library):

1. **Modifying the indicator** – Examples of this modification include the transformation of a depth-damage curve to account for the presence of property-scale resilience measures or the inclusion/removal of a variable within the Social Vulnerability Indicator (e.g. percentage of insurance uptake to account for the presence of financial assistance post-event). In this way a DRR is integrated directly into the assessment of vulnerability;
2. **Reducing the value of the indicator output** – Examples include the application of a percentage reduction or the subtraction of a reference value based on an assessment of the potential benefits of using a DRR;
3. **Recalculating an input value to an indicator, but without indicator modification -** In this case the DRR will change one of the inputs to an indicator (e.g. threshold level and hazard characteristic) and thereby affects the output of the vulnerability assessment; without changing the indicator itself. Examples of this include the presence of evacuation shelters within the assessment of the potential for risk to life. If evacuation shelters are present then the selection of the type of area present (an indicator input value) will change;
4. **Selection of an appropriate alternative indicator -** For some DRRs the type of receptor affected by the hazard event alters (e.g. a change in land use from residential property to public open space). For these situations it is appropriate to re-select the vulnerability indicator to reflect this change.

8.1 Sources of information

A range of sources of information have informed the instructions in the Library about how to include the role of DRRs within vulnerability assessment. Where possible existing approaches[179]

[179] Parker, D.J., Priest, S.J., Tapsell, S., Schildt, A. and Handmer, J. (2008) Modelling the damage reducing effects of flood warnings. Milestone report T10-07-12 for the Integrated Project FLOODsite, Enfield: Flood Hazard Research Centre. Available online at www.floodsite.net (accessed 25.03.2015)

[180] have been utilised; however examples of this type are limited. Technical information about certain DRRs[181] and benefit appraisal methodologies also provide examples of potential damage-saving benefits and thereby its mitigative effect on vulnerability. Previous events have also offered insight of the positive impacts of DRRs. For example, studies based on ex *post* data[e.g. 182 183 184] have indicated to what extent certain measures and actions have reduced damages in previous events and have thus informed the reduction values applied to damage data.

Users should also be prepared to discuss the potential effects of DRRs with experts and stakeholders, from their point of interest. Stakeholders or local experts may have more detailed information about the performance of existing DRR measures in previous events or are aware of particular circumstances in their locality which would mean that the approaches presented in the Library would not be appropriate or representative of the influence of DRRs. For instance, expert judgement may provide specific information about why one area is more vulnerable than another (e.g. high degree of social capacity or cohesion in one area and not another; the presence of a particularly vulnerable building material where collapse may be higher such as unfired brick[185]; the level of penetration of insurance to assist financial recovery). This advice might inform all three approaches to the inclusion of DRRs into vulnerability assessment, but in a number of ways: inform how an existing indicator might be modified based on their experience (e.g. the introduction of a variable into the Social Vulnerability Indicator); how the input to an indicator may change (e.g. the duration of the event will be reduced) or by how much the output of a vulnerability indicator should be reduced.

For circumstances where the presence of a DRR is considered particularly important and where data is unavailable or it is not deemed possible to modify the input to an indicator or the indicator itself; then it might be possible (and appropriate) to adopt a more relative or comparative approach for the location at risk. In this way, experts may suggest positively adjusting the output of a vulnerability indicator based on their knowledge about why one area is vulnerable and another less vulnerable. Due to the high specificity of these cases, it is not possible to include these within the Library; however this is an approach that users might want

[180] Priest, S.J., Wilson, T., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Fernandez-Bilbao, A. (2007) Building a model to estimate Risk to Life for European flood events. Milestone report T10-07-10 for the Integrated Project FLOODsite. Enfield: Flood Hazard Research Centre. Available online at www.floodsite.net (accessed 25.03.2015)

[181] JBA (2012) Establishing the Cost Effectiveness of Property Flood Protection. FD2657, final report Defra, London.

[182] Thieken, A.H., Muller, M., Kreibich, H. and Merz, B. (2005) Flood damage and influencing factors: new insights from the August 2002 flood in Germany. Water Resources Research, 41. 1–16.

[183] Kreibich, H., Thieken, A.H., Petrow, T.H., Muller, M. and Merz, B. (2005) Flood loss reduction of private households due to building precautionary measures – lessons learned from the Elbe flood in August 2002. Natural Hazards and Earth Systems Sciences, 5. 117–126.

[184] Kreibich, H., Muller, M., Thieken, A. H. and Merz, B. (2007) Flood precaution of companies and their ability to cope with the flood in August 2002 in Saxony, Germany. Water Resources Research, 43(3). 1–15.

[185] Priest, S.J., Wilson, T., Tapsell, S., Penning-Rowsell, E., Viavattene, C. and Fernandez-Bilbao, A. (2007) Building a model to estimate Risk to Life for European flood events. Milestone report T10-07-10 for the Integrated Project FLOODsite, Enfield: Flood Hazard Research Centre. Available online at www.floodsite.net (accessed 25.03.2015)

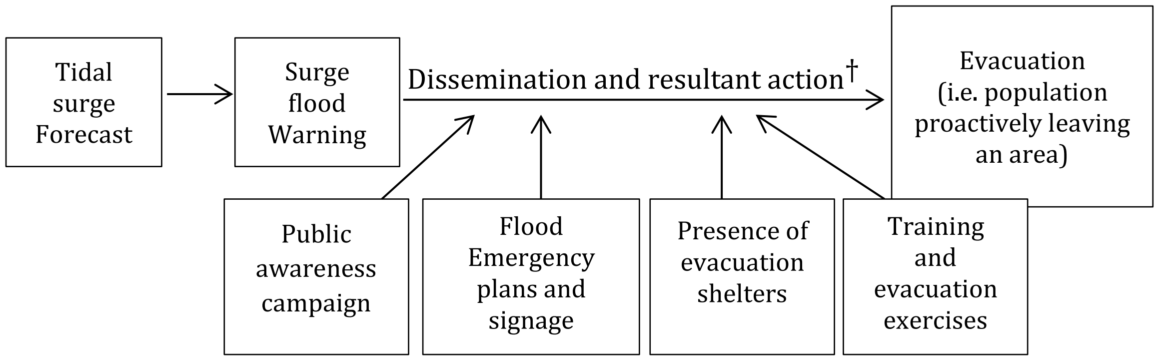
to adopt in some circumstances. When applied, the rationale needs to be clearly documented and justified when presenting the results of the vulnerability assessment.

There are many potential DRRs that might be utilised in the case of extreme coastal events and these are explored in more detail in WP4. It is important to note however, that only those DRRs which directly affect vulnerability are included in the Library (see Table 8.1 for those DRRs included). Consequently, those DRRs which affect the hazard or its characteristics (e.g. velocity, depth) such as coastal defences or artificial reefs will be included through their affect upon particular inputs to indicators (see approach 3 above). However, the Library does not assist in assessing how these measures may affect hazard characteristics; this should be undertaken as part of the hazard modelling.

Similarly, there may be DRR measures which affect the exposure of receptors (e.g. buildings, assets, people) to an event. Activities of this nature include development control, such as the removal of properties following an event (such as occurred following the impacts of storm Xynthia in 2010[186]), defences that entirely prevent areas from being affected, as well as during-event activities such as the proactive movement of cars, boats or livestock. These DRRs will influence the exposure to an event and in the most part have not been included within the Library as they do not affect directly a category of vulnerability or an indicator. The evacuation of people and land use change have been included for those indicators whereby it may modify input value of an indicator or when existing approaches have already included these as variables.

Often however, it is difficult to consider DRR measures in isolation as different types of measures are often reliant and interact with other measures in order to work operationally and to be effective in reducing the risk. Many DRRs may act as part of a complex chain of actions which may reduce overall vulnerability; an example of which is presented in Figure 8.1. However, although there is evidence to suggest that raising awareness of risk is necessary for effective emergency planning and that this will impact on the actions of residents during an event and the numbers of people who positively evacuate; it is very difficult to demonstrate and quantify the direct influence that a public awareness raising programme has upon a population's risk of sustaining fatalities.

[186] Kolen, B., Slomp, R. and Jonkman, S.N. (2013) The impacts of storm Xynthia February 27-28, 2010 in France: lessons for flood risk management. Journal of Flood Risk Management, 6. 261-278.



†Decision taken to evacuate may depend upon a number of issues which can be influenced by other DRR measures:

- Receipt of a warning/evacuation order (and in good time);
- Understanding of the warning/evacuation order;
- Acceptance of the warning or need to evacuate;
- Have a safe place to evacuate to and awareness of where these are located and a route to reach them;
- Ability to evacuate (i.e. have necessary transportation).

Figure 8.1: Examples of the complexity of DRRs working in combination to impact upon the percentage of the population evacuating prior to a tidal surge event

Where examples of including DRR chains in assessments of vulnerability exist, they have been included in the Library but these cases are rare. Therefore, the Library is primarily limited to situations where there is a single DRR measure influencing a single element of vulnerability. Furthermore, the degree to which the indicators are able to take account of the effectiveness of DRRs is variable. Some existing models do include reference to elements of DRR effectiveness (such as the reliability of flood warning[187], measure effectiveness and uptake[188]) and where appropriate these variables can be included. Additionally, damage reductions which are based on *ex post* data will to some degree take account of the effectiveness of measures and these will be reflected in the damage reduction values proposed. However, for others it is more difficult to include whether a DRR measure will act in the manner to which it was intended or be fully effective. In these cases it is important to try to learn from previous events and seek the advice of stakeholders involved in the implementation of disaster risk reduction.

[187] Parker, D.J., Priest, S.J., Tapsell, S., Schildt, A. and Handmer, J. (2008) Modelling the damage reducing effects of flood warnings. Milestone report T10-07-12 for the Integrated Project FLOODsite, Enfield: Flood Hazard Research Centre. Available online at www.floodsite.net (accessed 25.03.2015)

[188] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal. Routledge, London.

8.2 The inclusion of DRRs in the assessment of Systemic Vulnerability

Systemic vulnerability is inherently more complex than the other categories presented in the Library and similarly the inclusion of DRR measures also needs to be considered differently. The assessment of systemic vulnerability not only needs to include the vulnerability of particular assets (or groups of assets) but may also the vulnerability of networks or services to disruption. DRRs may therefore impact upon both of these elements. Within the context of systemic vulnerability it is also essential to consider DRRs more broadly and include those measures which offer risk reduction benefits through ensuring the continuity of systems or networks as this may be achieved through increasing the level of redundancy in the system (e.g. by duplicating assets) or through increasing connectivity.

The proposed approach to assessing systemic vulnerability in the Library includes the scope for including the effects of introducing DRRs through the different asset characteristics utilised (including likelihood of exposure, sensitivity, uniqueness, surrogacy, dependency or the estimated recovery time). The effect of a DRR measure on systemic vulnerability can be achieved by changing the output value of a particular asset characteristic being considered. As such, this may include:

- For asset characteristics where a scale is utilised (e.g. Likelihood of exposure, Sensitivity) moving from one output (e.g. high) to another (e.g. low);
- For the characteristic of uniqueness of an asset moving from ‘yes’ to ‘no’;
- For the characteristics of surrogacy and dependency potentially changing the description of the measures/dependencies which are present/absent;
- The category of repair or recovery time is provided as an integer and this should be modified (and reduced) where appropriate.

The mechanism for including DRRs for systemic vulnerability can be illustrated by using the case of an electricity distribution substation (an asset which is examined within the example provided in Appendix D). In this case, there is the potential to modify all of the measures of asset characteristics depending upon the type and nature of the DRR measure adopted. Of course it is also conceivable that a number of DRR measures may be introduced in combination and where appropriate (and possible) these can be represented within a revised systemic vulnerability assessment though the modification of the outputs of multiple asset characteristics.

If there are plans to build a permanent structural defence and the substation is located in the benefitting area then the output value attributed to the likelihood of exposure could be modified from ‘high’ to ‘none’ as the asset is no longer likely to be impacted. However, if the proposed DRR measure is the erection of temporary defence barriers just prior to an event, a user might decide only to move from ‘high’ to ‘medium/low.’ The difference in this case is that these types of defences offer a lower design standard than permanent structural defences, and therefore may not be fully effective or even fail in extreme events. Similarly, raising the whole substation or the circuity within a substation will also reduce the likelihood of exposure.

The value for sensitivity may be impacted by taking action at the scale of substation. For instance, constructing substation housing out of more resilient materials may in some circumstances reduce the sensitivity to the impact of flooding. If this was the case the inclusion of the DRR could be reflected by moving from a ‘high’ value of sensitivity to ‘medium’. However, there are few DRRs that can positivity impact upon reducing the sensitivity of electrical circuitry to water; once it is wet it is usually irreparably damaged. Therefore, preferred DRR solutions in this scenario would likely concentrate on keeping circuitry from being damaged or by increasing the resilience of the system to cope with one substation being affected.

One option to reduce systemic vulnerability owing to the flooding of an electricity substation would be to increase the redundancy in the system and thereby reduce the reliance on this one asset. Although this DRR might be prohibitively expensive if adopted widely, this may be a preferred solution for situations where those assets/services which rely on this unique asset are considered very important (e.g. hospitals). In the case of an electricity substation, this could mean duplicating the asset (an alternative substation) outside the likely area of impact which could then provide electricity to the prioritised asset/service if the first substation was impacted. By doing so, the asset characteristic of uniqueness would change from 'yes' to 'no'. A similar outcome would be achieved by increasing the connectivity in the existing system so that electricity could be switched at times when the substation was impacted. This may necessitate increasing the capacity of multiple substations (thereby increasing redundancy of the system) so that the network is able still able to cope if one or more substations were affected.

When an electricity distribution substation is flooded there may be a large number of households, businesses or other critical assets impacted. There is some scope for surrogate measures to be adopted but these will be at the individual property scale; rather than being used for the whole population affected. Petrol or diesel powered electricity generators may be employed and inputted into the systemic vulnerability template, but their effect will be variable depending upon availability and are likely to be concentrated towards high priority assets/services.

Ensuring that electricity supply can be switched remotely, rather than by having to manually visit an asset, may reduce the dependency on other networks or assets. In this case the necessity of available personnel and access to the substation (e.g. routes may be affected earlier than the substation itself) are removed; and can be likewise removed from the systemic vulnerability assessment.

Having an effective emergency plan and also spare cables/equipment on standby may be effective measures to reduce the time taken to repair and recover service. Furthermore, there may be other options (e.g. the types of materials used to construct substations) or again by raising equipment higher above the likely threshold of flooding (e.g. so that the substation only has to be switched off during an event, rather than being materially damaged) that will positively affect the time taken to repair.

Table 8.1: The DRR measures included in the Library mapped onto the categories of vulnerability

Disaster-Risk Reduction Measure		Description	Vulnerability category
Pre-event land-use adaptation	Change of the land use of an area	Movement from vulnerable types of activities to less vulnerable activities	Built environment Population Ecosystems
	Change the type of crops farmed	Use of more tolerant crops	Ecosystem
	Raising the ground floor height of a property	Reduces the depth of water in a property	Built Environment
	Individual property resilience measures (wet flood proofing) (e.g. use of materials less susceptible to damage, putting circuits higher in the property)	Reduces the susceptibility of properties to damage and therefore reduces the cost and time to repair	Built Environment
	Passive individual property resistance measures (dry flood proofing) (e.g. flood proofed doors, self-closing airbricks, Non-return valves)	Will prevent water entering a property, up to a particular depth. Even if fails, it may increase the time available to take further damage saving actions	Built Environment
During-event DRR measures	Contingent/Active individual property resistance measures (dry flood proofing) (e.g. flood gates, inflatable flood barriers, flood skirts)	Will prevent water entering a property up to a particular depth but requires activation to be effective. Even if fails, it may increase the time available to take further damage saving actions	Built Environment
	Moving or evacuating assets and/or contents, including personal possessions, business stock or equipment	Reduces the amount of contents in direct impact with the flood waters	Built Environment

	Flood warning	Enables people to take action to find safety or to take damage saving action. This link relates to risk to life whereas other flood warning dependent DRRs (including warning-dependent resistance measures, moving or evacuating assets and/or contents, evacuation of people and pumping out of water) are dealt with in the appropriate cells	Built environment Population Ecosystems
	Evacuation of people from an area and the presence of evacuation	Removal of people prior to an event or providing them with a safe location (maybe targeted to specific groups or not untargeted)	Population
	Presence of evacuation shelters	Provides a safe haven for population during an event; particularly in those areas with risk activities	Population
	During-event search and rescue	May be able to remove people from risky situations and reduce the numbers of fatalities	Population
Post-event and recovery DRR measures	Presence/absence of insurance or compensation scheme	Provides a degree of financial recovery	Population
	Access to a good healthcare	May impact upon the long term health of a population in the post-event recovery period	Population
	Presence of effective social welfare	Provides financial assistance in relation to the direct or indirect consequences of an event	Population
	Presence of official/local community/volunteer groups trained to assist with recovery activities	Provides assistance (e.g. clean up/rebuild/knowledge) to the local population following flood events to recover	Population
	Post-event shelters and temporary accommodation	Reduce the health impacts immediately after the event as well as providing assistance and advice – may have an impact on long terms recovery	Population
	Pumping out of water	Reduces the permanence of water, which might prevent or reduce ecosystem loss	Built Environment Ecosystems

9 Appendices

Most of these appendices provide additional guidance or information on a specific vulnerability indicator or system.

Appendix A: Some examples of Social Vulnerability Indicators applied to flood events

Appendix B: Justification of variables used in the SFVI and transformation methods used

Appendix C: Social Vulnerability Indicators for Germany and Bangladesh

Appendix D: Systemic Impacts – Guidance document for electricity

Appendix E: Systemic Impacts – Guidance document for water supply

Appendix G: Systemic Impacts – Guidance document for rail disruption

Appendix F: Systemic Impacts – Guidance document for road disruption

Appendix H: Systemic Impacts – Guidance document for businesses

APPENDIX A: Some examples of Social Vulnerability Indicators applied to flood events

Table 1: General indices (non-coastal)

Index or approaches	Scales of assessment	Hazard type	Key variables included	Details and methods for aggregation	Author(s) Country
Social Vulnerability Indicator (SoVI) (USA)	USA counties	Environmental Hazard	11 variables: Personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race (African-American), ethnicity ((Hyspanic), Ethnicity (Native American), Race (Asian occupation), infrastructure dependence.	Using a factor analytic approach, 42 variables were reduced to 11 independent factors that accounted for 76% of the variance. These factors were place in an additive model to compute a summary score: the SoVI. It has been tested.	Cutter S.L., Boruff B.J. & Shirley W.L. (2003) Social vulnerability to environmental hazards. Soc Sci Q, 84, (1), 242–261.
Local Flood Vulnerability Index (Spain)	Municipal	Flood	Four variables (Flood hazard, exposure, prevention and preparedness) are measured by 16 indicators: historical flood marks, flood prone area, slope stability, inhabitants/km2, industrial plants/km2, cattle/km2, annual income/inhabitant, key infrastructure, flood regulations, flood prevention measures, past flood experience, information material, early warning system, emergency plans, fire	The four variables are measured by means of 16 indicators (binary; yes/no) (no weights assigned) Integration of factors (no weights assigned) by means of a GIS to a vulnerability map with an ordinal scale: low to high vulnerability. It has not been tested.	Spain Weichselgartner, J. & Bertens, J. (2002) Natural disaster reduction in Europe: a Don Quixotic project in the face of a changing world? In Brebbia, C.A. (ed.) Risk Analysis III. WIP Press,

Index or approaches	Scales of assessment	Hazard type	Key variables included	Details and methods for aggregation	Author(s) Country
			department, hospital.		Southampton, pp. 233-242
Social Vulnerability Index (SVI) (Germany)	County	Flood	Fragility: elderly persons above 65 years per total population. Socio-economic conditions: unemployed persons and graduates with only basic education per total population; apartment living space per person Region: degree of urbanity or rural area, measured by population density and the number of apartments with 1-2 rooms per total number of apartments.	The SSI is an index that is aggregated by equal weighting and simple summation from three main indicators of social susceptibility. It has been tested.	Germany Fekete, A. (2010) Assessment of Social Vulnerability for River-Floods in Germany, Doctoral thesis, University of Bonn, Germany
SoVI Lite	Census tracts (South Atlantic Division, USA)	Flood	They test various variables from the full version of SoVI.	Lighter version of SoVI (2003). Downscaled from county to tract scale. Series of distinct metrics and approaches was used to construct simplified versions of the original SoVI (less indicators). It has been tested.	USA Cutter, S.L., C.T. Emrich, D.P. Morath and C.M. Dunning (2013). Integrating social vulnerability into federal flood risk management planning

Index or approaches	Scales of assessment	Hazard type	Key variables included	Details and methods for aggregation	Author(s) Country
					J Flood Risk Management 6. 332–344
Community based risk index.	Indonesia	All	They divide the Index in 4 factors: Hazard (probability and severity) Exposure (Structures, population and economy) Vulnerability (Physical, social, economic and environ meal) Capacity and measures (physical planning, social capacity, economic capacity and management}	Each factor has assigned certain indicators. In total the Index consists of 47 indicators. In order to standardize all values, each of the indicators is assigned a value (1,2 or 3) according to the category achieved. Then a weighting system is applied in relation to the hazard which is analysed. The indicators of each factor are added separately. Finally the scores for all the 4 factors are added to obtain a final result (the Risk Index)	Bolin, C. and Hidajat, R. (2006) Community-based disaster risk index: Pilot implementation in Indonesia. In: Birkmann, J. (2006) Measuring vulnerability to natural hazards United Nations University Press. Tokio.

Table 2: Indexes for coastal vulnerability

Index or approaches	Scales of assessment and country	Hazard type	Key variables included	Details and methods for aggregation	Author(s) and Country where applied Country
Coastal Social Vulnerability Score (CSoVI)	County (USA)	Floods	Adds these variables to Cutter's (2003) SoVI: dune height, barrier type, beach type, relative sea level rise, shoreline erosion accretion, mean tidal range, mean wave height.	Applied to beaches in the USA.	Boruffa Bryan J., Christopher Emricha, and Susan L. Cutter (2005) Erosion Hazard Vulnerability of US Coastal Counties. Journal of Coastal Research: Volume 21, Issue 5: pp. 932 – 942.
Multi scale Coastal Vulnerability Index	National Local Authority Site level (Northern Ireland)	Coastal erosion	Coastal characteristics sub-index (resilience and susceptibility of the coast to erosion), coastal forcing sub-index (forcing variables contributing to wave – induced erosion and a socio-economic sub-index (population, roads, cultural heritage, railways, land use, conservation status	Multi-scale vulnerability index to investigate implication of spatial scale in depicting coastal hazard risk, coastal vulnerabilities for national, local authority and site level. It has been tested.	McLaughlin, Suzanne and Cooper , Andrew (2010) A multi-scale coastal vulnerability index – a tool for coastal managers? Environ mental Hazards, 9.
Coastal City Flood	City	Coastal	Index is divided in 3 components:	Based on exposure,	Balica, S. F., N. G.

Index or approaches	**Scales of assessment and country**	**Hazard type**	**Key variables included**	**Details and methods for aggregation**	**Author(s) and Country where applied** **Country**
Vulnerability Index (CCFVI)	(comparison of 9 cities around the world)	flooding	1.Hydro-geological 2.Socio- (cultural heritage, population close to coastline, % disable <14 and >65, awareness and preparedness, shelters) Economic (Growing coastal population, recovery time, km of drainage) 3.Politico-administrative component	susceptibility and resilience to coastal flooding. It combines multiple aspects of a system into one number. Each dimensionless indicator is normalised on a scale 0 to 1 Indicators which belong to the exposure and susceptibility factors are multiplied, and then divided by those which belong to resilience. Results are shown on a scale from 0 to 1. Not tested.	Wright, F. van der Meulen (2012) A flood vulnerability index for coastal cities and its use in assessing climate change impacts, Nat Hazards. 64:73–105

APPENDIX B: Justification of variables used in the SFVI and transformation methods used

Table 1 shows the variables used for the index and explains the rationales for the selection of each of them and Table 2 gives the transformation method used for each of the variables.

Table 1: Rationale for the selection of characteristics for the SFVI[189]

Characteristics	Rationale
Elderly (Aged 75+)	The age of 75 was chosen because epidemiological research has shown that after this age there is a sharp increase in the incidence and severity of arthritis (and other conditions) and this illness is sensitive to the damp, cold environmental conditions that would follow a flood event.
Lone parents	Previous FHRC research has shown that lone parents are badly affected by floods because they tend to have less income and must cope singlehandedly with both children and the impact of the flood, with all the stress and trauma that this can bring.
Pre-existing health problems	Research by FHRC has shown that post-flood morbidity (and mortality) is significantly higher when the flood victims suffer from preexisting health problems.
Financial deprivation	The financially deprived are less likely to have home-contents insurance and would therefore have more difficulty in replacing households' items damaged by a flood event (and it would take longer).

Table 2: Variables and transformation method needed to apply SFVI[190]

Variables		Transformation method
a	**Unemployment:**	log natural (x + 1)
b	**Overcrowding:**	log natural (x + 1)
c	**Non-car ownership:**	square root
d	**Non-home ownership:**	square root
e	**The long-term sick:**	square root
f	**Single parents:**	log natural (x + 1)
g	**The elderly:**	log natural (x + 1)

[189] Tapsell, S.M., Penning-Rowsell, E.C., Tunstall, S.M. and Wilson, T. (2002) Vulnerability to flooding: health and social dimensions. Phil. Trans. R. Soc. Lond. 360. 1511-1525.

[190] Ibid.

APPENDIX C: Social Vulnerability Indicators for Germany and Bangladesh

Social Susceptibility Indicator (SSI) (Germany)

The SSI is an index that is aggregated by equal weighting and simple summation from three main indicators of social susceptibility:

• Fragility: elderly persons above 64 years per total population

• Socio-economic conditions: unemployed persons and graduates with only basic education per total population; apartment living space per person

• Regional conditions: degree of urbanity or rural area, measured by population density lower/higher than 150 persons per km^2 and the number of apartments with 1-2 rooms per total number of apartments (These indicators are explained in the "Demographics" page).

The SSI identifies counties in Germany with a potential strong or weak social susceptibility to floods.

Indicator creation:

The six input variables are normalized to values from 0 to 1 and by simple summation the three indicators are created. The SSI contains value ranges from 1.8 to -1.8 and is displayed in defined equal intervals in 0.2 steps. The indicators contain value ranges from -1 to 1 and are displayed in defined equal colour intervals in 0.1 steps.

Each indicator is calculated as follows:

$$\text{Indicator} = \frac{\text{Sum (Var pos)* - Sum (var neg)**}}{\text{N (Var)}}$$

INDICATOR 1 = Rate of residents age 65 and older

$$\text{INDICATOR 2} = \frac{\text{Floor space p.p. - (unemployment + graduates without Hauptschule[191] qualif.)}}{2}$$

[191] Secondary School / Junior High School

INDICATOR 3 = $$\frac{\text{Rural population - small apartments}}{2}$$

* Var pos = variables with positive factor loads

** Var neg = variables with negative factor loads

Variable ranges (min/max): 0 to 1

Indicator range (min/max): -1 to 1

SSI = Indicator 1 + Indicator 2 + Indicator 3

Low SSI counties are characterised by strengths towards floods (prevailing capacities for flood mitigation, for example, financial capacities for private preparedness measures and recovery by high income sources). They also have low population density which indicates less exposure to floods. Counties with high SSI are characterised by predominating weaknesses towards floods (lack of capacities and high degrees of susceptibility).

More information can be found in:

Fekete, A. (2010) Assessment of Social Vulnerability for River-Floods in Germany. Doctoral thesis, University of Bonn, Germany.

Grid-based approach for spatial vulnerability assessment to floods (Bangladesh)

This indicator consists of a GIS-based methodology for transforming census-based population and socio-economic data to grid-based data at relatively finer resolution (100 x 100 m population grids). The methodology is applied to one particular area of Bangladesh (Dacope, Khulna), but it is applicable to the whole country.

The following steps are followed to create this indicator. More detailed information and methods can be found in Roy and Blaschke (2011)[192].

1. Data collection

Population Census data can be obtained from the Bangladesh Population Census (2011). Information on where to download the data from is available in the library. Preparation of grid-based data at finer resolution

A GIS-based methodology is developed to transform Census population data of different *mauzas* (lowest administrative sub-units) to population grids (100 x 100m).

2. Selection of vulnerability characteristics and variables

The characteristics and variables used to create this indicator are shown in the table. It is suggested that those characteristics shaded in grey are considered for the development of a Social Vulnerability indicator of the same nature as that described in the Guidance.

3. Assignation of relative weights using a multi-criteria decision –making method (the Analytic Hierarchy Process (AHP)) tool in order to make priorities and assigning weights to the selected vulnerability characteristics and variables.

Table of characteristics and variables used for the creation of the grid-based approach

Characteristics	Variables
Population and age	Population density, Population aged 60 years, Population having any sort of disability, Dependency ratio
Livelihood and poverty	Number of unemployed people, People living below the poverty line, People engaged in agriculture, People engaged in small business, People engaged in household works
Health	Distance to nearest hospital, Distance to nearest primary health care facilities, Number of village doctors available
Water and sanitation	Households using pond water, Households using tube well water, Households using tap or filter water, Households having sanitary latrine, Households having no toilet facilities
Housing and shelter	Households having thatched houses using bamboo and mud, Households having houses using corrugated iron sheets,

[192] Roy, D. and Blaschke, T. (2011) A grid-based approach for spatial vulnerability assessment to floods: A case study on the coastal area of Bangladesh. In *GI4DM conference, Antalya*. Available at: http://www.isprs.org/proceedings/2011/gi4dm/pdf/OP49.pdf (accessed 25.03.2015)

	Households having houses using brick or concrete materials, Distance to nearest shelters
Roads and other infrastructure	Distance to major roads, Distance to minor roads, Distance to nearest growth centre or market, Proportion of people having electricity connection
Land use/cover	Agricultural lands, Settlements, River or water bodies,
Environment	Area under shrimp cultivation, Area having salinity intrusion
Gender	Female literacy rate, Sex ratio, Female workers engaged in non-agricultural works Coping capacity domains
Coping capacity domains	
Assets	Households having radios, Households having televisions, Households having fixed or mobile phones, Households having bicycles, Households having agricultural lands
Education and human resource capacity	Adult literacy rate, School attendance rate
Economic alternatives	Proportion of non-agricultural workers, Distance to nearest city or town

Appendix D Systemic Impacts – Guidance document for electricity

Functioning electricity systems are a crucial aspect of daily life, in terms of public health, economic prosperity and aspects of public safety and security. A severe storm could impact upon individual assets (substations, power lines etc.) causing extensive disruption to the electricity network and other power-dependent systems[193]. The cost of this disruption may stem from business interruption, goods spoilage, damage to equipment and the cost of the inconvenience to suppliers and consumers (in terms of a loss of business or compensation payments) further down the supply chain[194]. As Asgary and Mousavi-Jahromi (2010, 309) point out, information systems are now the very core most business processes: "if a mass storage device, a server, or critical network connection goes down, the business cannot function normally. In today's business world, the cost of downtime has increased considerably"[195].

Several recent flood events have resulted in power failures of differing degrees. In July 2007, the failure of Castle Meads sub-station in Gloucestershire, England left 12,000 households without electricity for 20 hours at an estimated cost of €35 million[196].On 28th February 2010, more than one million French household had no power due to storm Xynthia[197]. On 24 December 2013 three electrical sub-stations at London Gatwick Airport were affected by flooding resulting in 145 flights being cancelled and impacting over 13,000 passengers[198].

There are several steps to consider in conjunction with the main Library Template. When assessing the disruption to electricity supply it is important to:

- Identify all electricity assets (power stations and sub-stations) in the region (c. 100km of coastline);
- Establish the flood exposure and sensitivity for each asset – where the predicted depth is likely to cause operational failure – based on advice from experts;
- Establish whether the asset location is protected and to what extent. Also consider the condition of the defences;

[193] Ouyang, M. and Dueñas-Osorio, L. (2014) Multi-dimensional hurricane resilience assessment of electric power systems. Structural Safety 48. 15-24.

[194] Eto, J., Koomey, J., Lehman, B., Martin, N., Mills, E., Webber, C. and Worrell, E. (2001) Scoping study on trends in the economic value of electricity reliability to the U.S. economy. Consortium for Electric Reliability Technology Solutions. Available from: http://certs.lbl.gov/pdf/47911.pdf (accessed 20.02.2015)

[195] Asgary, A. and Yeganeh, M-J. (2011) Power Outage, Business Continuity and Businesses' Choices of Power Outage Mitigation Measures. American Journal of Economics and Business Administration 3 (2). 307-315.

[196] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2014) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal, London.

[197] Kolen, B., Slomp, R., Jonkman, S.N. (2013) The impacts of storm Xynthia February 27-28, 2010 in France: lessons for flood risk management. Journal of Flood Risk Management 6 . 261-278.

[198] McMillan, D. (2014) Disruption at Gatwick Airport, Christmas Eve 2013. Report by David McMillan to the Board of Gatwick Airport Limited, 26 February 2014. Available from: https://www.gatwickairport.com/globalassets/publicationfiles/business_and_community/all_public_publications/2014/mcmillan_report_feb14.pdf (accessed 01.02.15).

- Consider how the supply may be interrupted during a flood event. Particular importance should be given to assets which are 'unique' (i.e. supply cannot be re-routed or switched). Remember to consider assets outside of the flood zone also, as these may not be directly affected but could rely on other assets within the area of inundation[199];
- Ascertain the number of businesses and households likely to be affected by the disruption so a descriptive analysis can be performed and a monetary value estimated (see below).

Dependency between telecommunications and power should also be taken into account as some telecommunication terminals need an electric power supply to operate.[200] Where necessary, a systemic analysis of at-risk telecommunications networks should be undertaken using the same Template. A power failure can impact upon rescue and response capabilities. In some areas of Germany during the 2002 Elbe floods in Central Europe, most communication means did not work and it was usually hardly possible to find alternatives for communication between staff and field.[201]

Disruption to the electricity network

Electricity transmission and distribution systems are made up of many different types of equipment, including overhead lines, cables and transformers (substations). Overhead lines and underground cables are generally not susceptible to floodwater, although they can be susceptible to storm surge, erosion and wind damage[202]. Figure 1 shows a diagram of two typical electricity distribution networks.

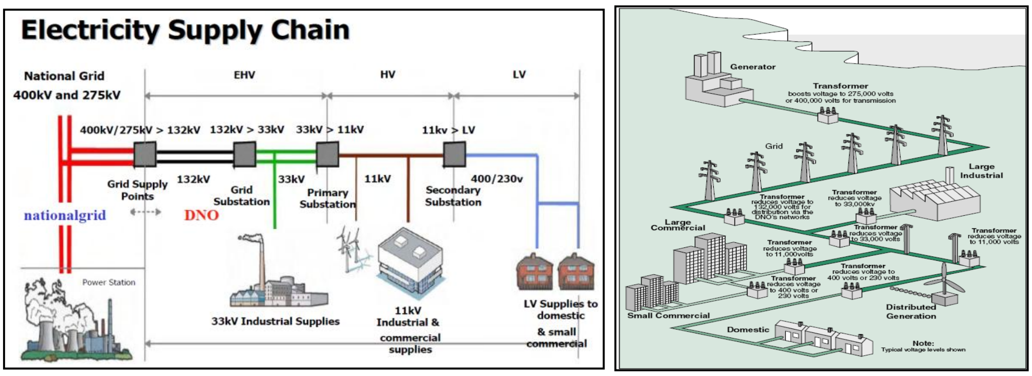


Figure 1 Typical electricity distribution networks[203] [204]

---

[199] Adapted from Energy Networks Association (ENA) (2009) Resilience to flooding of grid and primary substations. Engineering Technical Report (ETR 138), issue 1. Available from: http://www.naturalsols.co.uk/Ducts/Energy%20Networks%20Association%20%28ENA%29%20Substation%20Resilience%20to%20Flooding%20report.pdf (accessed 01.08.14).

[200] Gong, J., Mitchell, J.E., Krishnamurthy, A. and Wallace, W.A. (2014) An interdependent layered network model for a resilient supply chain. Omega, 46. 104-116.

[201] Richter, S., Reiner, K.H., Ulrike, L. (Undated) The Elbe Flood 2002: A case study on C2 systems and inter-organisational coordination. Prepared for the NATO SAS-065 Research Task Group. Available from: dodccrp.org/files/case_studies/Elbe_Flood_case_study.pdf (accessed 10.02.15)

[202] Energy Networks Association (ENA) (2009) Resilience to flooding of grid and primary substations. Engineering Technical Report (ETR 138), issue 1. Available from: http://www.naturalsols.co.uk/Ducts/Energy%20Networks%20Association%20%28ENA%29%20Substation%20Resilience%20to%20Flooding%20report.pdf (accessed 01.08.14)

[203] Energy Networks Association (ENA) (2009) 'Resilience to flooding of grid and primary substations', Engineering Technical Report (ETR 138), issue 1. Available from: Energy and Climate Change Committee ,

As a rule, the higher up the distribution chain, the greater the degree of redundancy. For example, power stations are not single points of supply and power generation can often be switched from other parts of the grid as loading demands. Super grid substations have at least duplicate circuitry equipment and therefore have high built-in redundancy. Substations with a single point of supply should be identified. Redundancy will usually decline with proximity to the point of customer supply. Particular attention should be given to grid and primary substations when considering resilience (see below for guidance on how to identify different types of substation). It is likely that flooding of distribution substations will create limited induced losses as customers supplied are also likely to be flooded and repairs to customer electrics/wiring are likely to be more protracted than repairs to the distribution substations themselves (usually within twenty-four hours)[205].

Governments may have a responsibility to ensure certain sectors and operations are given priority during disruption to services. These sectors will typically include major airports, railway operations, hospitals and key ports. Residential customers will often be a lower priority in such instances. The electricity assets, on which these sectors rely, should also be given an equivalent priority score.

Use the schematic diagram produced in Step 3 of the Template to identify where links in the system are likely to be severed. An example of how to approach this task is given in Figure 2. Here, the transformer (substation) shown with the red cross is no longer functioning. This is likely to cause a loss of electricity supply to the 'Small Commercial' business ('A' in the Figure) as no redundancy measures are in place (assuming no back-up generators are present). However, the 'Large Commercial' business (B) may still be able to function as it is served by a second substation (C).

the future of Britain's electricity networks, House of Commons, London, UK. Available at: http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenergy/194/19404.htm (accessed 01.08.14).

[204] Energy and Climate Change Committee (2010). The future of Britain's electricity networks. House of Commons, London, UK. Available at:

http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenergy/194/19404.htm (accessed 01.08.14).

[205] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2014) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal, London.

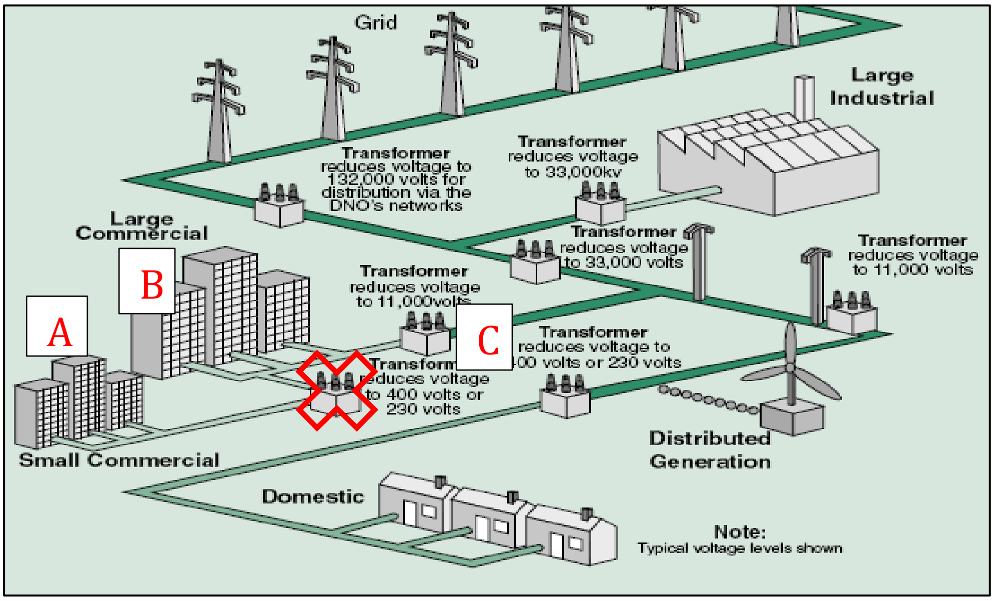


Figure 2 An example of system disruption[206]

Substation identification and the typical number of households supplied

Table 1 provides information to determine the type of substation in the case study site and the wider region. Although it is based on power assets in the UK, it is likely to translate to other European countries.

[206] Energy and Climate Change Committee (2010). The future of Britain's electricity networks. House of Commons, London, UK. Available at: http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenergy/194/19404.htm (accessed 01.08.14).

Table 1: Identifying Substations and population supplied[207]

Substation type	**Substation identification**	**Typical Voltage transformation levels**	**Typical size (Metres)**	**Typical numbers of customers supplied**
Grid (Super grid)		400kV to 132kV	250m x 250m	200,000 to 500,000
Grid (Bulk Supply Point)		132kV to 33kV	75m x 75m	50,000 to 125,000
Primary substation		33kV to 11kV	25m x 25m	5,000 to 30,000
Distribution substation		33/kV to 400/230V	4m x 5m	1 to 500

An additional method for estimating the number of households served by an electrical asset is by assessing the size of its perimeter fence. There is usually a direct correlation between the two, as presented in Table 2. Again, this is for the UK but will likely translate to other areas.

[207] After Energy Networks Association (ENA) (2009) Resilience to flooding of grid and primary substations, Engineering Technical Report (ETR 138), issue 1. Available from: Energy and Climate Change Committee (2010), The future of Britain's electricity networks, House of Commons, London, UK. Available at: http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenergy/194/19404.htm (accessed 01.08.14).

Obviously, if the local population is known to be less than estimated here, this must be adjusted accordingly.

Table 2 Households served as a ratio of substation perimeter fence[208]

Substation type	**Average perimeter fence**	**Ratio customers to metres of perimeter**
Grid (Super grid)	900m	250:1
Grid (Bulk Supply Point)	300m	183:1
Primary	110m	136:1

In addition to the descriptive analysis produced in Step 5 of the Template, It is possible to assign an economic value to the disruption to the electricity supply and this can be done in several ways. Energy companies may be liable for compensation payments for each day without power and users should contact electricity companies/providers or check their websites to ascertain the level and type of compensation policies in place. Households and businesses will usually receive different levels of compensation, due to their differing energy needs, and so an average figure should be ascertained for each. Users will also need to know the number of households and businesses affected by the interruption of electricity and the likely duration.

It is important to approach local businesses in order to ascertain the value of a day's interruption or disruption for the company and to find out if any surrogate measures are in place, such as back-up generators. Research suggests that the larger, multi-national, chain or franchise style businesses are more likely to have business continuity plans in place than small or medium, independent businesses[209]. See the Business Interruption section of the Library for more information on how to conduct a systemic analysis for Business.

[208] After Energy Networks Association (ENA) (2009) Resilience to flooding of grid and primary substations, Engineering Technical Report (ETR 138), issue 1. Available from: Energy and Climate Change Committee (2010), the future of Britain's electricity networks, House of Commons, London, UK. Available at: http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenergy/194/19404.htm (accessed 01.08.14).

[209] Parker, D.J., Penning-Rowsell, E.C. and McFadden, L. (2012) Business disruption and recovery planning in relation to coastal flood and erosion risks: theoretical dimensions and field survey evidence. Project Deliverable Report IDWT4.3, THESEUS research project (Innovative technologies for safer European coasts in a changing climate), FHRC, London.

Appendix E Systemic Impacts – Guidance document for water supply

With the disruption to the electricity network, disruption to the water supply network is a common example of critical services impacted during a natural hazard. The disruption of water supply may happen for various reasons. The impact of floods or erosion on the water supply infrastructures limiting the delivery of water is one of them. However the necessary control and maintenance of the drinking water quality standard is an important factor which may delay the service recovery beyond the repair time.

The most recent example of large disruption in Europe happened in Summer 2007 in England when the water supply to 350,000 consumers was lost for up to 16 days[210] [211] following the flooding of the Mythe Water Treatment Plant (Figure 1). The damages to the plant were limited by a complete shutdown of the facility before the flooding. However the necessary water drinking standard controls have created delays in the restoration of the services. During the 2011 floods in Brisbane (Australia) water supply was also lost for some communities but despite the major challenges water was alternatively supplied by other water distribution networks. The reduction in water supply was mainly due in this case to an interruption of water treatment operations due to high level of water turbidity and other problems following successive floods in Brisbane, Queensland Australia[212]. Similarly in 2004 following Typhoon Aere, the water turbidity in stream flow and in reservoirs exceeded the treatment threshold and, as such, none of the regional treatments were able to process raw water causing a 19-day public water supply outage[213]. During Hurricane Katrina, around 170 drinking water facilities were damaged or made inactivate by the surge. As an alternative to water supply to certain areas in order to avoid health impacts, a water purification unit for contaminated and salt water of a capacity of up to 200,000 gallons of purified water per day was sent as an emergency procedure[214]. Local contamination of the aquifers through damaged well sites also occurred threatening, in the short–term, the quality of the groundwater[215].

---

[210] Chatterton, J., Viavattene, C., Morris, J., Penning-Rowsell, E. and Tapsell, S. (2007) The cost of the Summer 2007 floods in England. SC070039/R DEFRA/EA report.

[211] Severn Trent Water (2007) Glousestershire 2007: the impact of the July Floods on the water infrastructure and customer service. 64p.

[212] Espada, R.J.R., Apan, A. and McDougall, K. (2013) Using spatial modelling to develop flood risk and climate adaptation capacity metrics for vulnerability assessments of urban community and critical water supply infrastructure. Spatial modelling of flood risk and climate adaptation capacity metrics – 49th ISOCARP congress 2013. 12p.

[213] Chou, N.F.F. and Wu, C. (2010) Reducing the impacts of flood-induced reservoir turbidity on a regional water supply system. Advances in Water Resources 33. 146-157.

[214] Homeland security and counterterrorism (2006) The federal response to Hurricane Katrina: lessons learned.

[215] Tomaszewski, J.D. and Lovelace, K.J. (2007) Effects of Hurricane Katrina's storm surge on the quality of shallow aquifers near the Northern Shoreline of Lake Pontchartrain, Southeastern Louisiana. In: Farris, G.S., Smith, G.J., Crane, M.P., Demas, C.R., Robbins, L.L., and Lavoie, D.L. (2007) Science and the storms—the USGS response to the hurricanes of 2005: U.S. Geological Survey Circular 1306. 213-220.

Figure 1: The Mythe Water Treatment Plant flooded during the Summer 2007 in UK[216]

A water supply system aims to deliver a defined quantity and quality of water from a water resource to the consumers at certain pressure. A water supply system is mainly composed of pumping systems, treatment plants, water distribution pipes and storage units (example in Figure 2). However the spatial distribution, the number and type of assets and the complexity of the network differs greatly from one case to another as various factors interfere in the system development, including the availability, type and quality of water resources, the historical development of the cities, its management and its governance etc. Therefore at a regional scale in certain cases more than one systemic analysis might need to be conducted as the water supply might be organized around multiple, local and independent supply systems (e.g. at municipal level). In other cases only one analysis of a larger distribution system will be required (group of municipalities).

In order to characterize the vulnerability of the water supply system we recommend considering the following key "assets" in the analysis: the water resource (WR), the water pump (WP), the water treatment plant (WTP), the water distribution pipes (WDP), the water storage unit (WS) and the consumers (C). Other assets may be included if relevant for the systems.

[216] Image source: British Geographical Society/Natural Environment Research Council http://www.bgs.ac.uk/research/engineeringGeology/shallowGeohazardsAndRisks/flooding/july2007.html (accessed 01.03.2015)

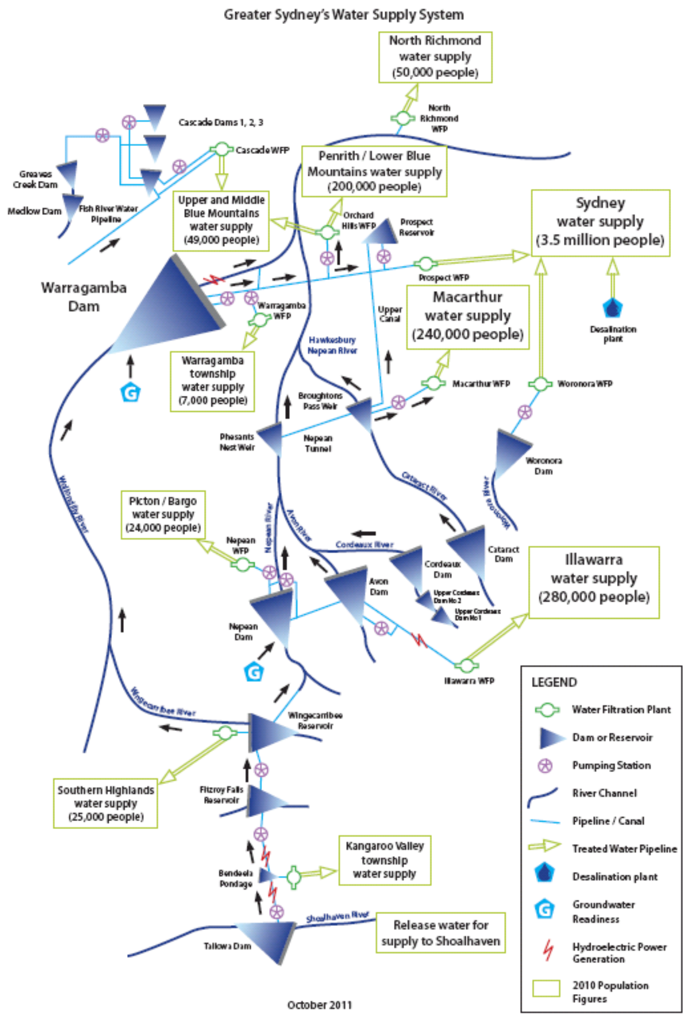


Figure 2: The supply network for Sydney and surrounding areas[217]

Various water bodies can be used as water resource (WR), i.e. river, spring, groundwater, sea etc. Available information on the different waterbodies can be obtained by approaching the water authorities and are publically available. Dams and large reservoirs can be included in this group but might be managed by a private organisation. The entire system or some of the consumers may depend on one water resource, others on multiple resources which are mixed within the pipe network or at the treatment plant. However, even if multiple sources are used, certain sources are more important in terms of quantity and quality; and a failure of one may compromise the whole water distribution. The main threat to the water resource is its potential contamination from flooding leading to the deterioration of the quality in the short or long-term.

To a limited extent and depending on the type of contaminant the deterioration of water quality might be mitigated by the treatment facility. The water treatment plant and the water resource pumping station are the assets most exposed and susceptible to flooding. Discussions with the asset managers are necessary to clearly identify their vulnerability, the precautionary measures

[217] http://www.bom.gov.au/water/nwa/2011/sydney/ (accessed 19.02.2015)

and the procedures in place in case of a hazard threat and a failure of these assets. The assets are also dependant of other factors such as power, manpower and access. Pumps can also be found elsewhere in the distribution network. Water storage units may include reservoirs and water towers used within the distribution network, which are unlikely to be exposed due to their relative elevation. The pressure in the water distribution pipes limits a potential contamination from flood water and their susceptibility can be considered as low from flooding, but erosion may damage a pipe. However the main recurrent problem in the water distribution system is the local failure of pipes and valves. One main reason is the water hammer effect which results from a change in water pressure in the water transmission system and may induce bursting or collapsing of the pipe[218]. Such change in pressures may be induced by erosion or by the failure of the pumping system; but it remains difficult to predict without detailed modelling assessment.

The potential number of consumers and their water consumption needs should also to be assessed in the process. Different groups of consumers may need to be considered as the consequences of water disruption will vary from one user to another. Whereas households and certain economic activities may adapt and limit their consumption or handle short disruption by the simple use of bottled water or bowsers (Figure 3), other consumers, such as hospitals or water dependant manufacturing industries (e.g. food, textile), will have to cease their activities unless greater emergency procedures are available. Overall, the assessment should inform the potential number and location of consumers without water and the duration of water shortage. If the water supply is defined as a depending factor in another system (e.g. business, emergency services), this relationship should be clearly explained in the evaluation and conveyed in the other systemic assessment.

Figure 3: Water bowser[219]

The shortage of supply can also been expressed in economic terms using a compensation value, often expressed per household/business per day. In the UK, this is approximately €15 for households and €70 for businesses. Compensation values and practices are likely to vary between countries and perhaps regions. Local water authorities/companies should be contacted in order to obtain this information. The extra cost of using alternative source of water can also be used.

[218] Wang, R., Wang, Z., Wang, X., Yang, H. and Sun, J. (2014). Water hammer assessment techniques for water distribution systems. Procedia Engineering (70) - 12th International Conference on Computing and Control for the Water Industry, CCWI2013.1717-1725.

[219] Image source: Atlas OPS http://www.atlasops.com/flood_response.htm (accessed 01.05.2015)

Appendix F Systemic Impacts – Guidance document for road disruption

A full assessment of the disruption and financial losses resulting from the flooding or erosion of roads is complex as it requires assessing the numbers of vehicles potentially affected and an appreciation of how their journeys may change under such conditions.[220] As this is above and beyond the scope of the RISC-KIT project, this guidance document will provide only general methods to assist with the assessment of road inundation and the completion of the Systemic Template within the Library.

Figure 1: The River Ouse Washes near Earith, Cambridgeshire, UK.[221]

Users should not only concentrate on roads themselves, but other aspects of the network such as tunnels, bridges and embankments. An analysis of the network may well have been undertaken – not necessarily specific to flood or storm events – which could be adapted for the purposes of this project.

Driver behaviour on the road network can have implications on other indicators, such as risk to life. In the Gard Region of French, 40% of the victims of flash floods during the last fifty years were motorists. One 8th and 9th September 2002, five people drowned in their cars and about two hundred emergency vehicles were trapped on inundated roads and destroyed or seriously damaged.[222]

It is unwise to consider assessing road disruption unless:

- One or more main/strategically important road is inundated: this can have far-reaching consequences for business (supply of goods and products interrupted, employees unable to access place of work etc.), for public institutions (lack of access to schools and hospitals etc.) and for emergency responders and evacuation procedures. And/Or;

---

[220] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2014) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal, London.

[221] Image source: Richard Humphrey, http://www.geograph.org.uk/photo/1734545 (access 05.02.2015)

[222] FLOODsite (2007) Road Submersion Model, France Gard Pilot Forecasting Of Road Submersions. Available from: http://www.floodsite.net/html/cd_task17-19/road_submersion_model.html (accessed 05.02.15).

- The duration of inundation will cause an unacceptable level of disruption to road users and the wider community. This ‘unacceptable’ level of disruption will vary from site to site should be ascertained in consultation with a range of stakeholders.

The key factors for estimating traffic disruption include:

- The number of roads likely to be impacted and their importance;
- The presence and distance of alternative (non-inundated) routes;
- The flood duration or erosion extent (specifically, how long is the road likely to be impassable?).

Road reconstruction costs following flooding will vary depending upon the type and scale of damage, the type of road impacted and the location of the required repair (Penning-Rowsell et al. 2014). As a guide, in the UK unit reconstruction costs for resurfacing a local road range between approximately €20/m^2 for a quiet road to up to approximately €65/m^2 for a busier road (which require a thicker surface layer and road works may need to occur at night or off-peak and thus incurring overtime costs)[223] [224]. In the Netherlands and Belgium, the maximum damage values given per metre of road are as follows: €1,930 for national trunk roads, €1,300 for motorways and €360 for other roads[225].

Unless significant direct damage is expected, for instance where road bridges may be affected or structural damages from erosion, it is wise to concentrate solely on the indirect losses caused by the disruption from road closures.

Traffic disruption

Floods in Germany in 2013 lead to more than 4,800 hours of traffic delays with road obstructions observed in a total of 89 districts[226]. The winter 2013 floods in Somerset, UK caused a main thoroughfare to be closed for a total of 69 days costing the county an estimated €2million[227]. In the aftermath of Hurricanes Katrina and Rita, the road network along the US Gulf Coast was severely impacted. Some sections of road were out of action for over 6 months and the cost of repair and recovery exceeded €550 million[228].

---

[223] Hertfordshire County Council (undated) An Introduction to Highway Maintenance. http://www.hertsdirect.org/docs/pdf/i/inthighmaint.pdf (accessed 01.02.1

[224] Conway County Borough Council (2013) Resurfacing. http://www.conwy.gov.uk/doc.asp?cat=9089&doc=28955 (accessed 01.02.15)

[225] Kok, M., Huizinga, H.J., Vrouwenfelder, A.C.W.M. and Barendregt, A. (2004) Standard Method 2004. Damage and Casualties caused by Flooding. Highway and Hydraulic Engineering Department.

[226] Bessel, T. (2014) Analysis of road traffic obstructions caused by the central European flood in June 2013 in Germany. Geophysical Research Abstracts, 16, EGU2014-16653 2014, EGU General Assembly 2014.

[227] Somerset County Council (2013) Closure of the A631. Transport Economics Review, Somerset County Council, Taunton.

[228] Grenzeback, L.R. and Lukmann, A.T. (2007) Case Study of the Transportation Sector’s Response to and Recovery from Hurricanes Katrina and Rita. Cambridge Systematics, Inc., Cambridge, Massachusetts.

The financial cost of road traffic disruption can be calculated using methods developed by Penning-Rowsell et al. 2014[229]. In order to do this, the following information is required:

- **The number and type of vehicles per hour** on the road section(s) under normal conditions. These data can be obtained from local authorities where traffic surveys have been undertaken. The type of vehicle (car, lorry etc.) is important as each type is likely to have different 'resource costs' (see below). An average cost can be estimated for all vehicles;
- **The value of time and operating costs per vehicle (€)**: this is an estimate based on the value of an individual's working time to the economy (using wage contributions) and the cost of operating the vehicle (fuel and maintenance etc). These data are produced for a variety of reasons, for example when costing new traffic calming measures (new road layouts, bypasses etc.) and may already be available locally. An estimate based on average wages and the cost of fuel could also be used. Data from the UK is provided in Table 1, as a guide;
- **The likely flood duration (hours)** obtained from modelling different scenarios;
- **The additional distance (km)** which must be travelled in order to divert around an inundated section of road (Figure 2).

Once this information has been obtained, we can apply the following equation to calculate the traffic disruption costs:

CD = VD * AC * D

where:
CD is Estimated costs incurred during disruption (€)
VD is Number of vehicles delayed per hour
AC is Additional cost per vehicle (€)
D is Flood duration (hours)

A comprehensive assessment would take into consideration the reduction in speed on the diversion routes as a result of flood-affected traffic joining these routes, but this is time-consuming and perhaps unnecessary here.

[229] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2014) Flood and Coastal Erosion Risk Management: A Handbook for Economic Appraisal, London.

Table 1 Total Value of time and vehicle operating costs, based on UK data (Source: Department for Transport, 2013)[230]

Value of time and vehicle operating costs (Euro Cents per kilometre)								
Speed (km/hr)	**5**	**10**	**20**	**40**	**50**	**80**	**100**	**120**
Car average (p/km)	339	173	91	51	43	29	26	23
Large Goods Vehicles average (p/km)	398	207	111	62	53	40	38	35

As an example, suppose that **10,000** cars travel between Point A and Point B (Figure 2) each **hour** and will have to travel **50 kilometres** further but their average speed (50 km p h) will not be reduced. In this scenario, the cost of that flood event will be equal to **10,000** * **0.43** (the value per car, taken here from Table1) * **50** for each hour of the disruption due to flooding. If the flood lasts **10** hours, the costs of traffic disruption amounts to **€2.15 million**. In a major event, where the road network is severely impacted, these compensation values may no longer be appropriate as road users are likely to change their travel behaviour or use alternative modes of transport. This should be considered when analysing other transport systems and in the descriptive analysis in Step 5 of the Template.

For the regional analysis, each populated area can be considered as a 'node' or junction in the road network and this will prevent having to analyse every single minor road in the region.

[230] Department for Transport (2013) UNIT 3.5.6: Values of time and vehicle operating costs. In Transport Analysis Guidance (TAG), Department for Transport, London.

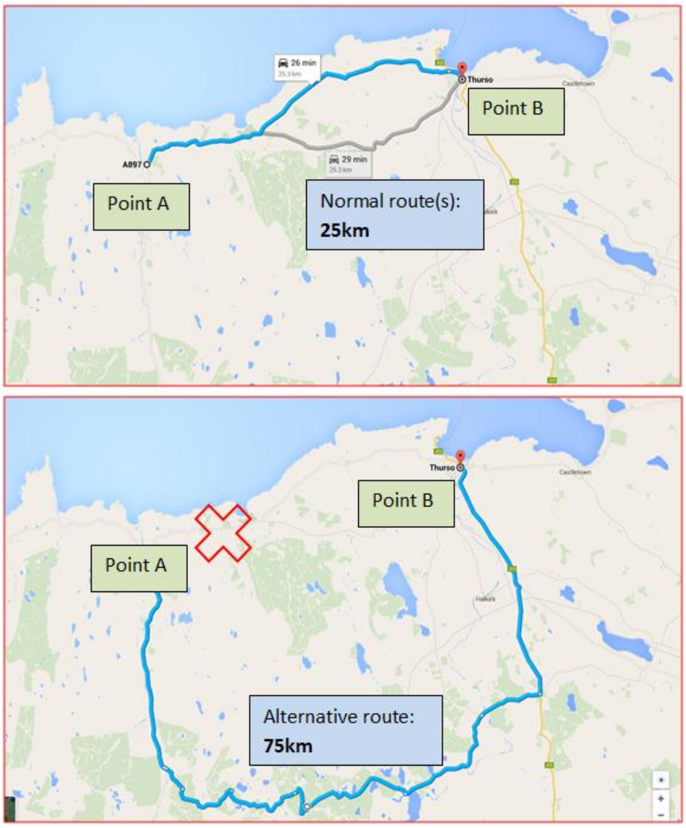


Figure 2: The inundated section of road is highlighted with a red cross and the only alternative route shown

In addition to the financial cost of the disruption per vehicle, users should also take into consideration any possible disruption to commercial or industrial activities. For example, if the main supply line to a key financial asset (a port, fishery etc.) is a road, this could have substantial impacts on that economic activity. Even if the main road itself is not flooded, other access points could prevent or slow-down access. Discussions with business owners should be undertaken to estimate the cost of such an interruption. In order to avoid double counting, it is important to separate out the road disruption costs from the business disruption costs which are assessed separately using the Business Disruption Template within the Library.

Many public buildings, such as hospitals, health centres and schools, and critical infrastructure assets require vehicular access in order to operate at full capacity and this must be considered within the narrative (Step 5 of the Template). Evacuation plans and emergency procedures should consider alternative options or routes if key roads will be closed due to flooding and this also needs to be discussed within the narrative.

Appendix G: Systemic Impacts – Guidance document for rail disruption

As for the assessment of the road network, a full evaluation of the disruption and economic losses resulting from the flooding or erosion of rail infrastructure is complex and time consuming. In-depth methods and guidance for assessing direct and indirect damages to railway assets is available[231] [232] [233] but the information provided here is simplified and aims to assist with the completion of the Systemic Template within the Library.

Figure 1: Dawlish rail line damaged due to 2014 coastal storms, Devon, UK.[234]

It is always worth finding out if an assessment of the local transport network has already been undertaken. This can then be consulted and improved upon (where necessary) in order to fulfil the requirements of the RISC-KIT project.

Two separate storm events in February 2014 caused extensive damage to the main rail line at Dawlish in Devon, England resulting in 7500 train service cancellations[235]. Extensive reconstruction work was initiated over a two-month period, including the rebuilding of Dawlish station and platform, installing over 20km of new cables, designing and installing a new temporary signalling system and replacing over 700 metres of track and ballast at a cost of €48

[231] Moran, A.P., Schöbel, A., Rachoy, C. and Thieken, A.H. (2010) Documentation of Flood Damage on Railway Infrastructure. In: Düh, J.; Hufnagl, H.; Juritsch, E.; Pfliegl, R.; Schimany, H.-K.; Schönegger, H.; (Eds.) Data and Mobility, Transforming Information into Intelligent Traffic and Transportation Services, Proceedings of the Lakeside Conference 2010. Advances in Intelligent and Soft Computing, 81. 61-70.

[232] Benn, J. (2012) Railway Bridge Failure during Flood in the UK and Ireland : Learning from the Past. Institution of Civil Engineers. Available from: http://www.ice.org.uk/ice_web_portal/media/events/railway-bridge-failure-during-flood-in-the-uk-v2-nov-12.pdf (accessed 01.02.2015)

[233] Penning-Rowsell, E.C., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. and Owen, D. (2013) Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal, Routledge, London.

[234] Image source: Western Morning News http://www.westernmorningnews.co.uk/LIVE-UPDATES-Rail-travel-hanging-thread-track/story-20563661-detail/story.html (accessed 10.02.2015)

[235] Devon Maritime Forum (2014) Holding the Line? Reviewing the impacts, responses and resilience of people and places in Devon to the winter storms of 2013/2014. A Summary Report from the Devon Maritime Forum. Available at: http://www.devonmaritimeforum.org.uk/images/stories/DMFdocuments/DMFmeetingArchives/2014Autumn/DMF%20Storms%2013-14%20Summary%20Report.pdf (accessed 10.02.2015)

million[236]. The closure of this section of the rail network effectively cut-off the south west of England to rail traffic. An upper estimate of the economic impact to the region from the mainline rail closure has been valued at €1.65 billion for the two-month closure[237].

Harsh winter weather conditions in Norway, Sweden, Switzerland and Poland in 2010 led to severe rail traffic disruption which in turn spread to other logistics channels, causing shippers and logistics operators to move freight away from rail to road carriage. As a result, railway revenues reduced due to the loss of high-value container cargo and long-term business prospects for international freight movement suffered[238].

Direct or physical damage can occur to rail infrastructure assets including track, circuits, embankments, signalling equipment, stations and trains. It is very difficult to provide an average or guide estimation for these losses as, unlike roads, rail assets vary significantly between countries. Users are advised to contact rail asset managers or similar in order to obtain information on infrastructure at risk and its location, level of susceptibility and likely repair or replacement costs.

Unlike road traffic, trains cannot usually be diverted and so services are likely to be either delayed or cancelled when a section of track or other essential rail asset is inundated or damaged by a coastal event. It must first be decided if the consequences of such an event will be sufficiently negative to warrant the investment of time and resources needed to the quantify the losses and the assessment of disruption. This can only be decided in conjunction with local stakeholders following a flood/erosion modelling exercise or after consulting historic event records.

Where the rail network provides an important access point to a key economic sector (such as a port or airport); it is recommended that an assessment be undertaken. Even if the critical asset is not itself located within the area of study, but the rail lines or rail infrastructure feeding such assets are, this should also be considered (Figure 2).

[236] Network Rail (2014) Dawlish railway reopens in time for Easter holidays as Network Rail's 'orange army' wins its war with the elements. News release, Friday 4 Apr 2014. Available at: http://www.networkrail.co.uk/timetables-and-travel/storm-damage/dawlish (accessed 01.02.15)

[237] Devon Maritime Forum (2014) Holding the Line? Reviewing the impacts, responses and resilience of people and places in Devon to the winter storms of 2013/2014. A Summary Report from the Devon Maritime Forum. Available at: http://www.devonmaritimeforum.org.uk/images/stories/DMFdocuments/DMFmeetingArchives/2014Autumn/DMF%20Storms%2013-14%20Summary%20Report.pdf (accessed 10.02.15)

[238] Ludvigsen, J. and Klæboe, R. (2013) Extreme Weather Impacts on Freight Railways in Europe. Natural Hazards, January 2014, 70(1). 767-787

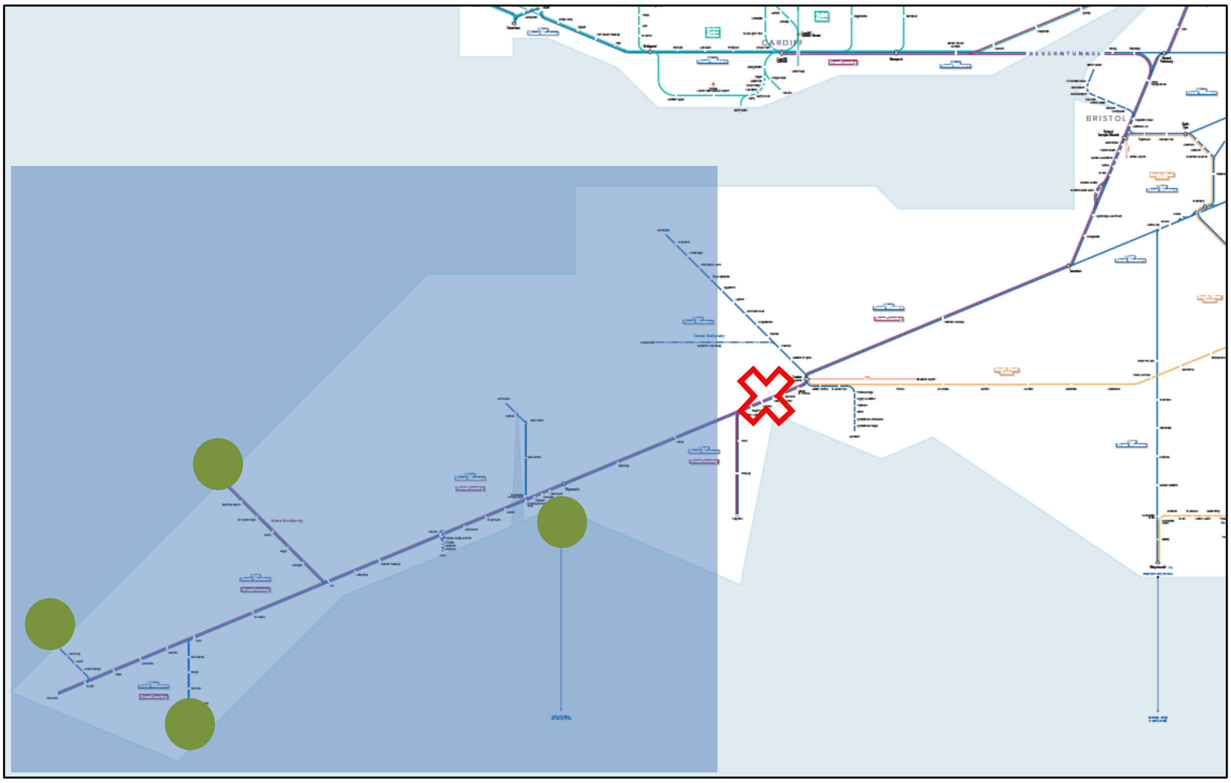


Figure 2: The inundation of one section of rail line at Dawlish, England (illustrated by the red cross) had serious consequences for rail services to other parts of the country (blue highlight). The green circles show areas of specific importance for commerce or tourism which were affected by the rail closure many miles away.

By completing Step 2 of the Systemic Template (listing the key components) the following information should be available to you:

- The location of rail assets (including track, stations, signalling equipment etc.) in the area of study;
- The exposure and susceptibility of these assets to flooding or erosion: Dora 2007 provides the depths at which rail infrastructure is impacted by flooding, based on guidance in the UK[239]. The equivalent information should be obtained locally or advice sought from experts to decide when speed restrictions or service cancellations are likely;
- The 'capacity' of the network: in this case the number of passenger services or the quantity of freight/goods passing through the network on a normal day.

It is then necessary to estimate the duration of the suspension to these services, the number of services impacted and the number of passengers on board or the cost of delays to freight/goods deliveries. This information can be difficult to obtain and will require discussions with rail authorities, regional government officials or engineers.

An estimate of the disruption cost could be based on the compensation values to passengers and freight companies or alternatively a value of time figure for each rail passenger and the cost of an interruption of economic activity which can be obtained from experts. As a guide, the UK

[239] Dora, J. (2007) Summer 2007: a Network Rail perspective. Proceedings of the 42nd Annual Flood and Coastal Management Conference, 3–5 July 2007, York.

Department for Transport values a UK rail passenger's time at €65.00 per hour, which costs the level of inconvenience (in the form of an amount the passenger would willingly pay in order to avoid a delay) and lost working time caused by a delay or cancellation (using average wage payments)[240]. This figure may be available locally if previous studies – not necessary specific to coastal hazards – have been undertaken or a surrogate measure could be employed, such as the value of time for a road passenger. Using the average number of passengers per train service, multiplied by the number of services affected per hour/day, this value of time per passenger can be used to produce an estimated disruption cost.

Where the suspension of services continues for many days, a value of time figure will be less useful as individuals will find alternative modes of transport. For example, train passengers may switch to the road network, if this is available (it too may be impacted), and this should be analysed within the road network systemic assessment. Prolonged disruption to the rail network, local businesses, the tourism sector, trade and industry etc. may begin to suffer, particularly if redundancy measures (for example, the switching of supply lines) are absent. Consultation with stakeholders will be necessary to obtain this kind of information.

As for the road network, a descriptive analysis of the situation may be of equal or perhaps a higher value to users than an estimated financial cost of disruption. This is why Step 5 in the Systemic Template is an important aspect of the assessment.

[240] Department for Transport (2012) UNIT 3.5.6: Values of Time and Vehicle Operating Costs. Transport Analysis Guidance (TAG), Department for Transport, London.

Appendix H: Systemic Impacts – Guidance document for business

The following steps should be considered when assessing the disruption potential of businesses:

- Identify the coastal business setting which best describes the site: there are 3 basic options and these are described in Table 1 in this Appendix;
- Establish the flood risk for the coastal location, particularly the likely extent of extreme flood events and the extent to which the location is protected;
- Identify the main components of the man-made and natural coastal infrastructure which may be damaged or temporarily lost (e.g. beaches, promenades, sea walls, piers, shingle banks, dunes etc.);
- Identify the boundaries of the locality or region in which business disruption is to be examined;
- Consider how damage to the coastal infrastructure is likely to impact businesses both directly and as a consequence of direct damage. Particular importance should be given to any businesses which are likely to be unique to the region. It is important to consider businesses outside of the extreme flood zone as these are more than likely to be adversely affected by damage to coastal infrastructure and/or businesses within the flood zone;
- Because of the spatial reach of business supply chains, consider the extent to which impacts may spread beyond the areal boundary selected.

It will also be necessary to decide on one of two possible approaches to vulnerability assessment.

Approaches

a) A low-intensity, secondary source approach

The first approach is a low-intensity one and may be used where resources are limited. Local knowledge may be used in the first instance. The local municipality is likely to have a unit which has a good deal of information about businesses, their size and inter-dependencies. Where necessary, contacts with the local Chamber of Commerce or other business stakeholder groups may be utilised to map out the likely supply chain linkages of the major businesses or business groups in the area. Assumptions will need to be made about some of these linkages and dependencies although some of them should be gathered through business surveys or other forms of stakeholder engagement and local research will be fairly obvious and may be worked out deductively.

b) A primary source business survey, evidential approach

This approach is more intensive and applicable where more resources are available. Once a) has been exhausted, data may be gathered through business surveys or other forms of stakeholder engagement and local research. By starting with the largest businesses it will be usually be possible to progressively identify supply chains to the point where further survey work becomes unnecessary.

Identifying the major businesses and their supply chains

It is necessary to identify the major businesses and groups of businesses within the coastal locality and the region in which it is located if the chosen boundaries are regional. Initially, the focus should be mostly upon the locality (including the businesses located in the extreme flood zone and those beyond it).

In the UK, for example, there are a variety of sources which allow businesses to be identified including the number of businesses in an area and their size. These include Local Authority data (Office of National Statistics Neighbourhood Statistics, and Regional data (BIS Business Population Estimates). In most areas Business Directories of one sort or another are likely to be available for this purpose. If necessary, by contacting the local municipal government it should be feasible to categorise businesses by size according to their number of employees. Local Chambers of Commerce may also be consulted for these purposes.

Two approaches are available to help the identification of business supply chains in a coastal business setting. Here it is important to focus only upon identifying the major supply chains (i.e. the ones which the greatest disruption potential), including any large and/or unique businesses in the region.

Other relevant information including LVA and GVA data

Columns 8-12 within Step 3 of the Library Template (henceforth: the Asset Matrix) require some basic information which either may become obvious or available through the identification of businesses and their supply chains explained above. However, information on estimated likely duration of disruption owing to an extreme event may well be best collected by asking specific questions about this either to those providing secondary source data or through business surveys. Similarly, data to allow the Recovery Factor (see below for an explanation of this factor) to be estimated (i.e. Column 16) is also best gathered in this manner.

For a Vulnerability Analysis (Descriptive and Quantitative) it is necessary to estimate Lost Value Added (LVA) (Parker et al., 1987, p45). To estimate LVA **,** GVA data will be needed. Business disruption is measured here in terms of lost Gross Value Added (GVA). It is necessary to acquire a measure of business activity or flows in order to gauge the impact of business disruption generated by an extreme event. Business activity or flow may be measured in economic terms using Gross Value Added (GVA). The most appropriate way to measure GVA is in terms of pre-tax earnings which represent a good proxy of value added. When the value of pre-tax earnings over the year is considered this is equivalent to the annual GVA impact. Although earnings post-tax are a more accurate measure of the GVA of workers to a local or regional economy (because taxes are examples of transfer payments within the economy) pre-tax earnings are a recognised metric for considering GVA impacts[241] [242].

Data is required on the average actual or projected earnings by business or industry category for your region. This is likely to be available in published form from secondary sources. For example, in the UK, these data are published as part of the Annual Survey of Hours and Earnings available from the Office of National Statistics. Again it is possible to acquire the necessary data by undertaking a business survey but this is likely to be much more resource-intensive. If all fails it may be feasible to use assumptions about average earnings in each business sector based on data or evidence which is available. It is the high-value businesses which should be focused upon mostly.

---

[241] Frontier Economics (2014) TOOLKIT for assessing the impacts of flood and coastal erosion risk management on the local economy, Joint Defra/EA FCERM R&D programme - project FD2662, Defra, London http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/FD2662_full_toolkit.sflb.ashx (accessed 20.02.15)

[242] Parker, D.J., Green, C.H. and Thompson, P. (1987) Urban Flood Protection, a project appraisal guide. Gower Technical Press, Aldershot, England.

Steps to be undertaken for a Vulnerability Analysis (Descriptive and Quantitative)

Step 1

Calculate the business size split within each business sector using local or regional data. For example, in the UK, the BIS provides business population estimates by business size and by business sector for each region of the UK. Business size is defined by the number of employees. For example, in the UK businesses are categorised into 21 single-digit "Standard Industrial Classification" codes. It is likely that secondary source data will be available for the locality or region according to a) some form of business sector based standard industrial/business classification and b) size as measured by the number of employees. If all fails it may be feasible to use assumptions about the likely distribution of businesses by size for each business sector adopting a 'pyramidal' distributional model.

Once these data have been identified they should be cast into three business size categories for the purpose of this analysis:

Size	Number of employees
Micro	0-9
Small/Medium	10-249
Large	250+

Enter the results into Column 7 of the Asset Matrix.

Step 2

Acquire earnings per employee per annum for each business sector by business size.

An extract of the data required could look like the following (see columns A-D below):

A	B	C	D	E	F	G
Business Sector	**Business size category**	**Average number of employees per business**	**Average earnings per employee. Euros per annum**	**Estimated total duration of repair/reinstate- ment or return to pre-event levels business**	Recovery factor	Value of lost working hours per business during the period of disruption. Euros per annum
Food and drink	Micro	5	30,000	9 months (39/52)	0.5	56,250
	Small/Medium	132	31,000	9 months (39/52)	0.5	1,534,500
	Large	400	33,000	9 months (39/52	0.75	7,425,000
Accommo	Micro	3	22,000	9 months (39/52	0.5	24,75049,500

dation (i.e. hotels, bed and breakfast etc.)	Small/Medium	12	25,000	9 months (39/52	0.5	112,500
	Large	-	-	9 months (39/52	0.65	-

NB. The data is this table are hypothetical and are not associated with the data in the Asset Matrix (Step 3) in the Library Template

Enter the results (i.e. in Column D above) into Column 14 of the Asset Matrix.

Step 3

Calculate the value of lost working hours per business during the period of disruption.

In order to calculate this value of disruption, as measured by GVA, it is necessary to multiply average employee numbers (column C above) by average earnings (column D above), and then by the proportion of the year that the business would likely to be disrupted in each size category (column E above). These columns correspond to Columns 6, 14 and 13 in the Asset Matrix). Note that it does not matter if the expected period of disruption is more than 12 months because the GVA value required is an annual one.

Step 4

Next, multiply the number of businesses in Column 7 of the Asset Matrix by the Value of lost working hours per business and then multiply the result by the Recovery Factor (Column F above, corresponding to Colum 16 in the Asset matrix). The result is entered into Column G above which corresponds to Column 17 in the Asset Matrix. The value entered is the potential GVA lost as a result of flood disruption. The Recovery Factor is a value which describes the amount of business lost over the period of business disruption. Note that the number of businesses is arranged by three size categories and this leads to a figure for the value of lost working hours per business for each of these. It is necessary therefore to undertake this calculation separately for each size category the number of businesses in each size category.

How to estimate the Recovery Factor

Not all business is likely to be lost by a business disrupted by a flood. Business owners and managers are usually very keen to return their businesses to 'normality' as soon as possible. Estimate the Recovery Factor using data from business surveys or secondary sources, or make as realistic as possible assumptions about this factor. The Recovery Factor relates to the different paths by which businesses are able to return to pre-flood levels of business (Figure 1).

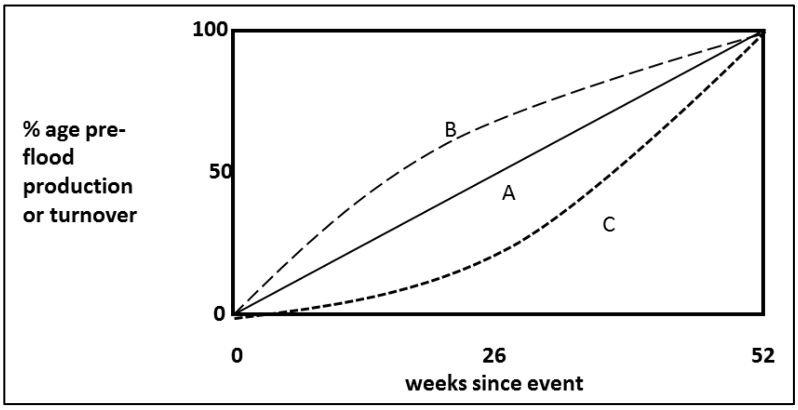


Figure 1: Illustration of different paths of recovery of business to pre-flood levels

In Figure 1, curve A represents a constant rate of recovery of business over a 52 week duration (some businesses may need less than 52 weeks). A business that takes the path of curve A will begin to recover some business immediately after the flood and will have reached 100% recovery by the end of week 52. Some businesses may recover less satisfactorily as in the case of curve C. In this case by week 26, a business will only have recovered to 18% of the pre-flood level, but then the rate of recovery increases until 100% recovery is reached by the end of week 52. A business which recovers business quite rapidly after the event may be represented by curve C. It is possible that some businesses may not be able to recover at all until the end of the 52nd week and conversely some may be able to return to pre-flood levels of business immediately.

A business that follows curve A or similar will have a Recovery Factor of 0.5 because only half of its business is lost over the period of disruption (in this case 52 weeks). By integrating the area beneath curves B and C it is possible to calculate the amount of business lost in each case. A business for which the path of business recovery is described by curve B will recover more of its business. So it's loss owing to disruption is less than in the case of curve A. In the case of curve C the Recovery Factor will be approximately 0.2 whereas in the case of curve B it would be approximately 0.65.

Large businesses are likely to be able to call upon the more resources to aid flood recovery than SMEs, and large businesses that belong to a business group or corporation are more than likely to be able to return to full production or turnover more rapidly than SMEs.

If there is evidence that one or more business has adopted a robust business continuity plan (BCP) to combat flood disruption, then this is likely to reduce the disruption period and it may well also have a positive impact on the Recovery Factor. The disruption reducing impacts of BCPs – actual or potential – may be allowed for or estimated in this way.

Step 5

Total the GVA values at the foot of Column 17 to arrive at a measure of the total estimated value of business disruption. This is the financial loss likely to be suffered by the business community.

Step 6

Vulnerability narrative (for the completed Asset Matrix in the Library Template)

Vulnerability analysis (Descriptive and Quantitative)

The principal inputs to the system are the beaches and associated infrastructure and dunes which are the magnets for holiday-makers and tourists which visit and stay in the town. These assets are in the front line and highly exposed to high sea levels, storm surge and accompanying wave attack. The beach huts are also at high risk but most of the businesses have a low direct exposure because they are located on higher ground which would not be flooded. If the beaches and associated infrastructure and dunes are seriously eroded by one of more storms, then the town will lose its fundamental attractions. Ability to recover varies between businesses with the large Food and Drinks businesses have the highest ability to recover quickly. The number of people visiting and staying in the town is likely to be seriously affected.

Local businesses which are highly dependent on tourism and on one another (in two-way dependency) will be badly affected for at least one entire season and reinstatement of man-made and nourished beach assets may take years to complete. There will be a knock-on effect to local businesses which supply hotels etc. The total GVA likely to be lost in the town as a result of the event is estimated to be Euros 14.7million per annum during the period of disruption. The vast majority of this disruption loss will be experienced in three high-value business sectors: Restaurants and cafes (Euros 1,7m), Holiday Camp (Euros 7.4m) and Food and drink (Euros 2.3m). By comparison the value lost by disruption in the accommodation sector is relatively small. Only one of these high-value business sectors is directly exposed to flooding (Restaurants and cafes – low exposure), while the others are not directly exposed to flooding.

As there appear to be quite a few alternative, similar assets within the region, the town's financial loss is likely to be compensated to some extent within the region by financial gains, unless the alternative coastal resorts within the region are also struck similarly by an event. The analysis assumes that businesses do not possess effective business continuity plans designed to reduce the period of flooding disruption. If firms do possess such plans and can implement them effectively, then this will reduce these losses to some extent.

Table 1: Typology of coastal businesses and closely related assets

Typology of coastal businesses and closely related assets	
There are a number of commonly found types of coastal business location, including the following: 1) Beach frontage urban area (e.g. town) and tourist resort; 2) Port and related commercial and industrial zones; 3) Coastal harbour(with or without marina) and related urban area.	
(1) Beach frontage urban area and tourist resort (e.g. Bocca di Magra, Italy) The likely natural and man-made coastal infrastructure and business assets are likely to include some or all of these:	
Infrastructure assets	**Business assets**
Beach	Food and drinks outlets
Promenade	B&Bs and hotels
Dunes	Shops
Piers	Seaside attractions (e.g. fun-fairs)

Access roads/car parks	Transport (e.g. ferry, coach, train)
Road/rail routes	Agricultural businesses
Wetlands	Fishing, shell-fish extraction
Nature Reserves	Campsites
(2) Port and related commercial and industrial zones (e.g. Port of Zeebrugge, Belgium, Kiel Fjord, Germany)	
Infrastructure assets	**Businesses assets – 1st tier**
Deepwater channels	Roll-on/Roll-off handling – freight businesses
Breakwaters	Break bulk cargo handling businesses
Piers/quays	Passenger handling businesses
Docks	Container handling businesses
Dams/gates	Fuel (Gas, LNG, LPG) refineries
Crainage	Distribution/logistics
Marinas	Military installations (e.g. Navy)
Yacht and boat moorings	
Business assets – 2nd tier Typically these may include any of the following industries: Food and drink, Chemicals, Building materials, Base Metals, Metal Products, Machine, Public Utilities, Waste, Tank Storage, other	
(3) Coastal harbour (with or without marina) and related urban area (e.g. Tordera Delta)	
Infrastructure assets	**Business assets**
Harbour walls or piers	Harbour Authority businesses
Marinas with moorings	Marina management businesses
Landing stages, pontoons	Car parks
Boat repair yards	Chandlers
Cranes	Restaurants and cafes
	Shops
	Tourist attractions
	Commercial fishing